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ACOUSTIC NOISE IN VEHICLES

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The extensive use of 2-way radio in the Fire Service and trucking industry is of relatively recent origin and it is probably for this reason that some of the operational difficulties peculiar to large vehicles are still present. It is ironic that the greatest difficulty in communications often lies in the transmission of intelligence from the loudspeaker to the ear. The severe noise problem in fire apparatus lead us to give this matter some closer scrutiny in order to find an approach toward at least a partial solution. Most of use in the communications field are reasonably familiar with fundamental sound measurements. However, for the benefit of those who may have had little recent contact with the subject, it might be well to review briefly a few of the ground rules.

The unit of sound pressure level is the decibel referred to 0.0002 microbar and the unit of sound power is the decibel referred to 10-13 watt. Unfortunately, a straight line relationship between sound pressure and apparent loudness does not exist. This relationship is greatly influenced by frequency and the presence of extraneous sound pressures as well as by the individual departure from the average human response. Examination of equal loudness contours (Fletcher-Munson Curves) will disclose the wide variation in apparent loudness of a sound in the presence of a second sound at various frequencies.

The unit of apparent loudness as judged by the human ear is the "phon". This unit is derived from the equal loudness contours and is determined by the level of pure tones at various frequencies which are judged by an observer to be loud as a given 1000 c p s tone. (See figure 1). For example a level of 10 db @ 1000 cycles corresponds to 10 phons. A 100 cycle note would have to attain a level of about 43 db to be rated equal in loudness. Therefor, a 43 db sound pressure level at 100 cycles has a loudness level of 10 phons. On the other hand, at 3000 cycles, a level of only 3 db also has a level of 10 phons. At a level of 120 db @ 1000 cycles the 100 cycle note level is 125 db and the 3000 cycle note is 111 db for the equal loudness figure of 120 phons. If bands of random noise are compared to the 1000 cycle note, the equal loudness contours no longer vary so much with change in the level of the 1000 cycle reference note and the frequency of the band is of greater importance in determining the equivalent loudness level. This is illustrated in figure 2.

In evaluating the psycho acoustic effects of a noise it is important to determine the noise spectrum distribution. The frequency has con-

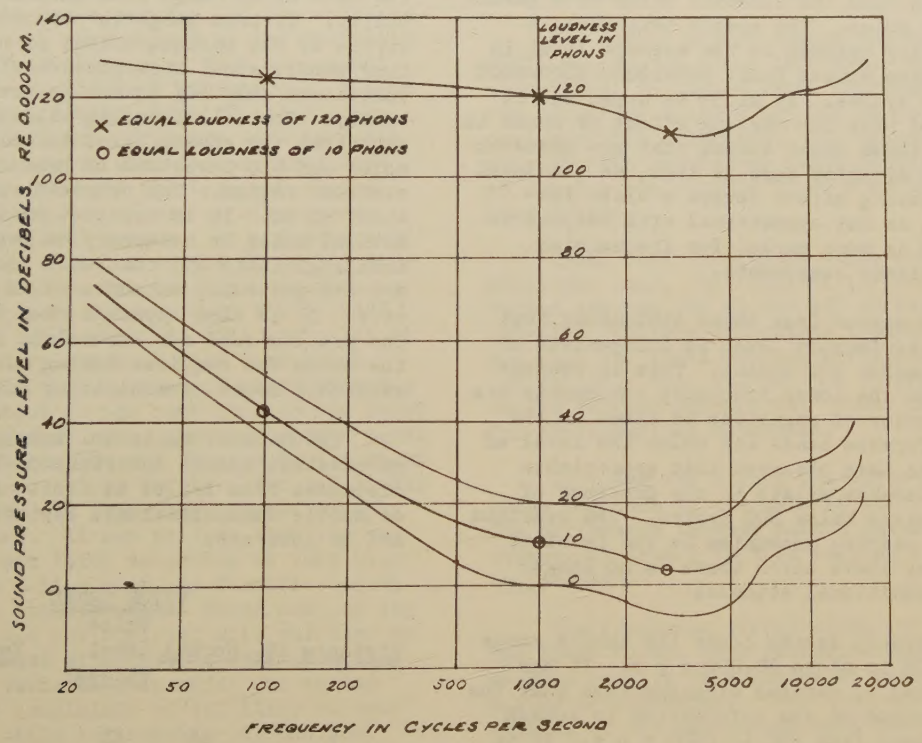

Fig. 1 - Equal loudness contours for pure tones.

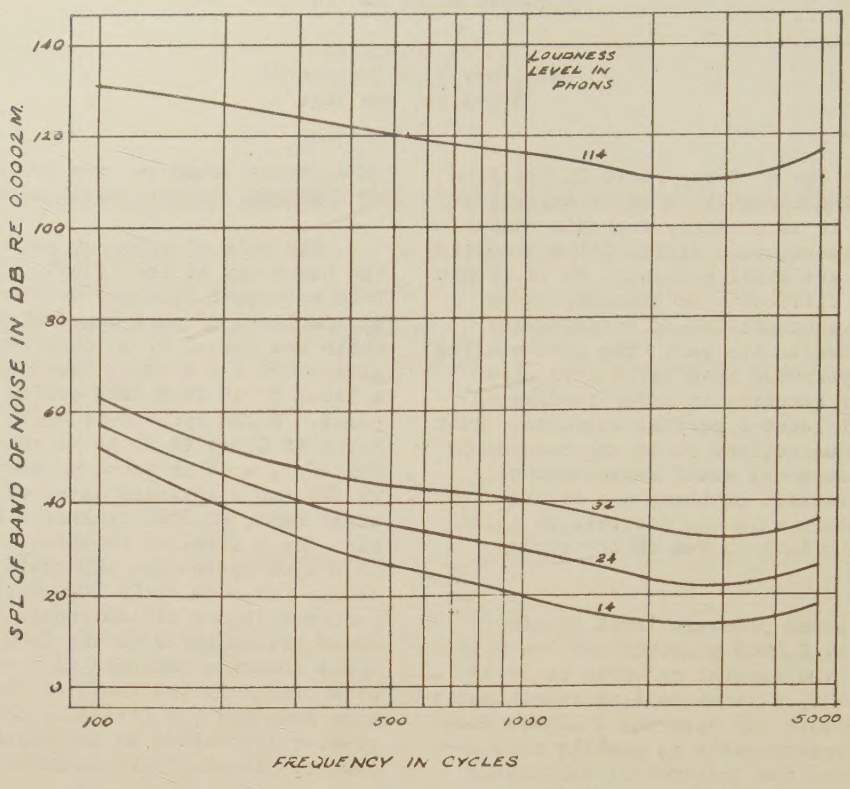

Fig. 2 - Equal loudness contours for narrow bands of random noise.

siderable bearing upon the speech interference level and also upon the niusance value of a particular tone or noise. The speech interference level is usually defined as the average level in db for the three octave bands 600-1200, 1200-2400 and 2400-2800 cycles. As might be expected, it has been found that the masking effect of sound is greatest for those other sounds that are close to it. A not so apparent fact is that, as the level rises, the masking effect covers a wider frequency range, is not symmetrical with respect to frequency and is more marked for frequencies above the dominant components.

It might appear from these statements that the speech interference level is independent of noise levels below 600 cycles. This is reasonably true when the lower frequency components are of the same order of magnitude as those in the speech interference bands and below the level of overload. We have observed that appreciable speech interference exists in the presence of high level noises below 300 cycles. The overload point of the hearing mechanism is the level at each frequency above which there is no longer response to additional stimulus.

Normal speech sounds cover the entire range from below 100 to above 10,000 c p s. It has been determined by various experimenters that the greatest portion of the information in speech lies in the band from 200 to 6000 c p s. It is also known that sound pressure levels vary over a dynamic range of about 30 db in any given subdivision of this band. It has been found that the full 30 db range will give 100% intelligibility. If this range is reduced to 15 db by virtue of the masking effect of noise, in any band subdivision, this portion of the band will contribute only 50% to the general intelligibility. For full intelligibility, it is necessary that the speech level be above the ambient noise and the threshold of hearing but below the overload region. The overload region begins at about 95 db. It is apparent that a fairly low ambient noise is necessary to permit 100% intelligibility and that such ideal conditions are not generally encountered in the mobile service. It is also apparent that the solution to the problem does not lie solely in outshouting the noise but requires taking advantage of all available means of minimizing adverse factors.

The General Radio Co. tabulates maximum permissible speech interference levels at varying distances from 1/2 to 24 feet. For the purpose of mobile communications, distances of 3 to 4 ft. are of interest.

	VOICE LEVEL			
Distance ft.	Normal	Voice level raised	Very loud	Shouting
3	55	61	67	73
4	53	59	65	71

If the 30 db range of level for maximum intelligibility is used as the criterion, it follows that maximum voice levels on the order of 103 db would be required at the 3 foot distance.

A number of experimenters have determined that, in the presence of high level noise in the neighborhood of 120 db, no increase in intelligibility occurs after the speech level reaches 105 db and that as the speech level rises beyond this point, the intelligibility definitely falls off.

A final point of interest in this review is the permanent effects of long exposure to high level noises. It is believed that continued exposure to very high levels of sound pressure results in temporary loss of hearing. It has been established by Davis that exposure to synthetic aircraft noise at a level of 110 db for 4 min. resulted in a loss of 6.4 db in the 500 to 7000 c p c bands. The same noise raised to a level of 130 db produced a hearing loss of 47.8 db when the exposure lasted 32 min. Complete recovery followed these exposures but his sometimes took several days.

All of the foregoing information is generally available in the publications of the Acoustical Society and in a number of excellent texts by Beranek and others.

In retrospect it is amusing that our study of noise in vehicular communications was originally prompted by our attempt to make noise rather than to eliminate it. We had had a number of accidents with our apparatus and the evidence indicated that they were caused by the inability of one unit to hear another as they approached intersections from different directions. It was our thought that a louder siren or other noise maker would provide the necessary warning range to provide the vehicles with the stopping distances necessary to avoid the frequent recurrence of collisions. A number of sirens were tested for sound level output. At a distance of 20 ft. the levels varied from 114 db to 126 db - mostly about 118 db - with the major components lying in the two octave bands from 600 to 2400 cycles. It was interesting to note that most of the sirens had directivity but of a somewhat undesireable nature. A number of units showed a a db greater output to the rear than to the front and 3 db less on each side. Another showed equal front to back ratios but a 3 db more in the right side and 6 db less on the left. A few had little or no directivity and propagated almost equally in all directions. It was evident that the vehicle operator was being subjected to very high noise levels at a time when his faculties could stand the least interference. Since most of the fire apparatus was not equipped with mufflers or any kind of exhaust silencer, we were generally aware that the vehicles were noisy and we had had a number of complaints of inability to hear radio messages while in transit. We did not, however, have any quantitative idea of noise levels. Measurements were made on a typical apparatus unit. The sound meter (General Radio Type 1551 A) was placed at the several operating positions, i.e., 2-Pump operators' positions and the driver's position. At idle speeds, sound levels of from 102 to 106 db were encountered. At engine speeds of 2500 RPM the levels increased to from 110 to 115 db. An efficient exhaust silencer was installed and a re-run of the tests was made. At idle speeds the maximum reading was 92 db and the minimum 84 db. At 2500 RPM the maximum reading was 104 db and the minimum 101. The vehicle was not in motion nor was any power being extracted from the engine other than its own frictional losses. The noise level with and without mufflers for all speeds as plotted against RPM were parallel and displaced by 12-13 db for all values up to 2000 RPM. From this point on there was a steep upward slope with the curve of the muffled engine rising even more sharply. Extrapolation of the curves toward higher speeds indicated that above 2800 RPM there would be no difference between the noise levels of muffled or unmuffled engines. (See figure 3). It is realized that this is probably not a wholly accurate or justifiable quantitative assumption but we believe that there is considerable validity in this conjecture. It was noticed that while the mechanical clatter of engine parts such as the magneto coupling, valve tappets, etc. was making a substantial contribution to the general noise level, the greatest offender was the cooling fan which was the dominant factor at the higher rotational speeds. The exhaust noise was predominantly in the lower bands from 20 to 300 cycles depending upon speed. On the other hand the fan noise contained components well above 1200 cycles.

The normal engine speeds for these vehicles while pumping is about 1800 RPM. Under pumping conditions, the noise level approximates 118db for unmuffled engines and 106 db for those equipped with silencers. The operator who is charged with maintained radio contact is positioned outside the vehicle about 8 to 10 ft. from the loudspeaker.

Under road conditions while driving at 20 miles per hour, the level at the drivers positions varied between 106 db and 120 db averaging about 110-112. While accelerating from 20 to 35 miles per hour the level reached sustained peak values of slightly over 130 db. At 35 MPH the level varied between 120-124 db. These figures were for the unmuffled apparatus.

At these low speeds the major portion of the noise was made by the exhaust and road rumble. The difference between smooth pavement and cobblestones was from 2 to 8 db varying with speed and roughness.

The frequency distribution was primarily in the lower bands. The following figures are average results of a number of tests with several pieces of apparatus. They are not, however, typical of any particular unit since there was a wide variation in the upper frequency bands due to reflections and ambient noise besides the characteristics of individual units. In any

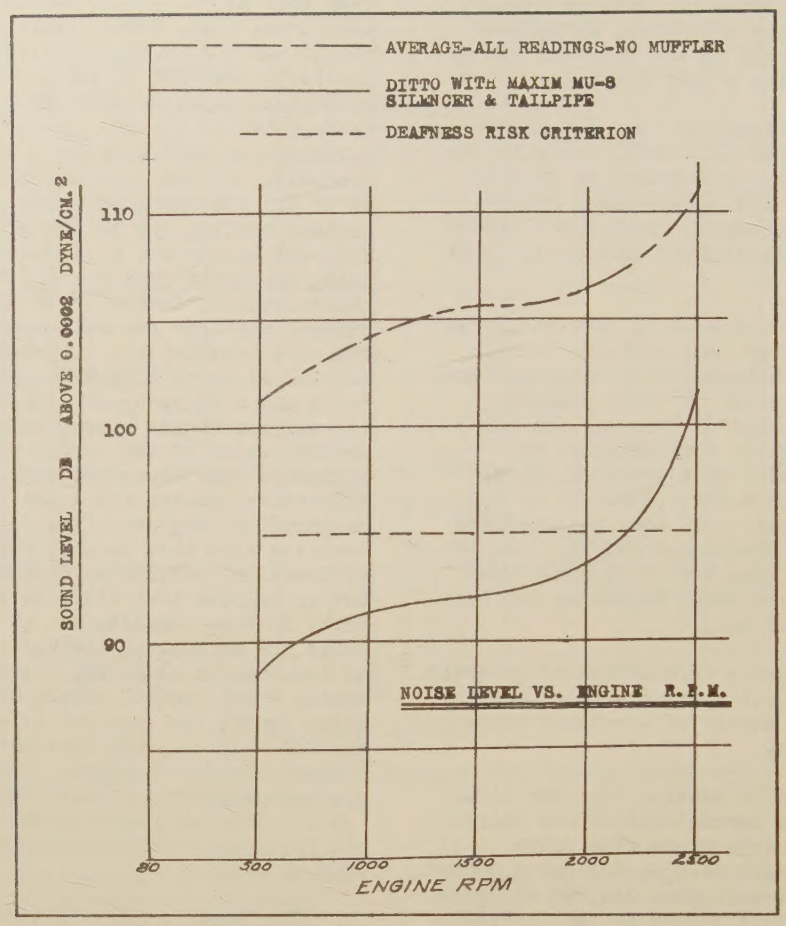

Fig. 3 - Noise tests on typical F.D. pumper.

event the figures represent a fair average of noise conditions encountered in fire apparatus in a metropolitan area.

20	-	75	cyc	-	118 db
75	-	150	"	-	116 db
150	-	300	"	-	96 db
300	-	600	"	-	80 db
600	-	1200	"	-	78 db
1200	-	2400	"	-	72 db
2400	-	4800	"	-	66 db

There was some fluctuation in values at street intersections where the reflecting surfaces of buildings were removed. These variations ranged from 3 to 6 db downward.

The results of these tests showed the impossibility of projecting the sound of sirens or other noise makers for any great distance in the presence of such high levels of ambient noise. It also gave rise to the conjecture that temporary deafness of the driver was a contributory factor in some of the accidents between two apparatus units.

It should be pointed out for purposes of clarification that, prior to the use of radio, the route taken by fire apparatus responding to a fire was known to other units responding and the intersection of their routes was also known. However, since the radio makes possible re-assignment while returning from a previous fire and the utilization of the fire companies for inspectional duties, the routes are no longer predictable with the result that collision between apparatus units is now a greater hazard. For this reason and as the result of other tests, all new fire apparatus is being equipped with exhaust silencers and, in addition to sirens, air horns of greater acoustic efficiency and directivity are being furnished.

We then became interested in noise levels in sedans which are used by the fire chiefs. Measurements showed that for speeds in the neighborhood of 40 MPH, the level was approximately 100 db increasing to about 105 db @ 60 MPH. In close proximity to buildings and other reflecting surfaces, the level rose from 1 to 3 db. Cobblestone pavements increased the reading from 100 to 105 db at 40 MPH. Closing all windows reduced wind and reflected noises about 3 db but did not

materially affect road and other low frequency noises transmitted thru the body of the vehicle. The frequency distribution of noise in the sedans was in higher bands than on the trucks. This would be expected due to the higher engine and vehicular speeds. The wind noise was considerable above 50 MPH and varied appreciably from one make of vehicle to another.

It is the purpose in this discussion to raise some questions rather than to answer them. It is our subjective observation after conducting these tests - which are admittedly not extensive and certainly far from complete - that the mobile communications industry is not doing the best possible job with the knowledge and materials at hand. It is also true that the automotive industry can certainly improve its product to the point where it will not require re-design on the part of the user to permit normal speech levels at reasonable speeds.

Aside from the usual wind and engine noises, the tire noise was observed to be appreciable and was greatly accentuated by the reflections of curbs and highway dividers. It was also apparent that the wind noise under the car due to various projecting parts cutting the air stream was high and manifested itself as a continuous "whoosh". Undercoating the vehicle reduced the higher frequency components but was of little value in the lower bands. These observations were not quantitatively substantiated because the separation of the noises emanating from these various sources constitutes a job of considerable magnitude and would be a long term project in itself.

The average mobile unit has an audio output geared to the police prowl car for which it was originally designed. There have been some modifications in the past several years designed to raise the output power from the previous optimistic 1 watt to 1 1/2 and 2 watts. This was not accompanied by any reduction in distortion.

When we are dealing with speech interference levels in the order of 60 to 65 db for sedans and 75 to 80 in heavy trucks, it should be apparent that advantage must be taken of every factor that can be utilized to improve the intelligibility.

We know that the band from 200 - 6000 is required for full intelligibility. The compressed band of 300 - 3000 cycles as used in the mobile communications field conveys only limited intelligence and requires the use of code words to identify consonants and other weak speech parts which cannot be completely identified in so narrow a band. This is true under even ideal listening conditions. It is doubly true in the presence of high noise levels where the threshold of hearing is appreciably raised and the ideal 30 db range is severely curtailed.

It may not be apparent to the casual observer that identification of speech parts is appreciably degraded in the 300 - 3000 cycle band because we are accustomed to recognize these components in combination with the more easily understood formants of lower frequency. If we depart from conventional speech and spell out sounds such as "p" "t" "s" "f" etc. the difficulty in identifying each one as distinct from another will be readily appreciated.

We were interested in determining the level of audio power required to provide acceptable performance. The sound level output at various frequencies was measured for 3 types of loud speakers in common usage. These were the re-entrant horn type, the short horn and the conventional 4" round cone speaker in a louvred metal housing. For inputs of 1 watt, 2 watts and 3 watts into the loudspeaker, sound level measurements were taken at a distance of 3 feet.

	Long Horn Input			Short Horn Input			Cone Input		
	1w	2w	3w	1w	2w	3w	1w	2w	3w
	Output db			Output db			Output db		
200	87	90	96	85	87	90	93	97	98
600	100	102	105	98	103	105	98	100	103
1000	110	110	113	102	106	106	90	95	95
1500	107	110	113	109	113	115	95	98	99
2000	104	107	110	106	108	111	100	101	105
2500	113	116	118	113	116	119	105	108	109
3000	108	109	112	107	110	112	92	94	96

There is little to choose between the long and short horn types except that the conversion efficiency of the long horn is better in the vicinity of 1000 cps by about 6 db. The short cone has certain physical advantages such as mounting ease and stronger mechanical structure which more than offsets the slight acoustical advantage of the long horn at a particular frequency - especially one which does not contain the more critical speech components.

The cone speaker's performance was rather poor by comparison at all except 300 and 600 cycles - its conversion efficiency was from 6 to 10 db below the others. For this reaon it had a rather muddled sound. This effect is accentuated in systems where the base transmitter, pick-up receivers or both are operated over cabled telephone pairs which are not equalized and undesireable attenuation of the higher frequencies occurs before the audio reaches the transmitter or the loudspeaker.

The results obtained take no account of the effect of reflections which are, of course, an influencing factor in closed vehicles. It is rare that the loudspeaker is located closer to the operator than 3 ft. and, in the case of large trucks, 5 to 6 ft. is a more probable figure. This reduces the sound level by about 5 to 6 db.

It was found by testing several vehicles that average levels to be expected at the ear of the vehicle operator would be about 96 db @ 1 watt, 99 @ 2 watts and 102 @ 3 watts for the short horn speaker. These figures are subject to some variation depending upon the structure of the vehicle and the location of the loudspeaker relative to the dashboard.

If we analyze these figures in the light of some of our known facts, i.e., a maximum level of 105 db in the presence of high ambient noise, a speech interference level of 75 to 80 db and a 30 db range in level above the speech interference level for full intelligibility it appears that the 3 watt output most nearly meets the requirement.

There is another point which we found to have significant weight in influencing the intelligibility of mobile units and this has been taken rather lightly by various manufacturers. It concerns distortion figures. It is, of course, no secret that distortion adversely affects intelligibility but there appears to be some doubt as to how much distortion can go undetected or is permissable. The figure 10% is generally accepted as the industry standard for mobile receivers. 10% is a noticeable figure even at discrete frequencies and, when applied to complex speech patterns, contributes greatly to loss of comprehension. If we take into account the transmitter distortion, nonlinear wire lines and intermodulation distortion - we find that the system intelligibility is usually lower by an appreciable amount than what one might infer from the 10% figure. In one large, recently designed fire radio system the audio output specifications called for 3 watts at a maximum of 7% distortion. At levels appreciably below 3 watts the distortion was below 5%. The intelligibility is markedly superior to that in systems using conventional equipment and it appears that some of the theories projected are borne out in application.

The distortion figure is conventionally measured at 1000 cycles into a resistive load at set deviation. While this may be a convenient method of defining the term, it represents a somewhat unrealistic method of performance evaluation. Speech is not a 1000 cycle note, the deviation is anything but fixed and the loudspeaker is most certainly not a resistive load for all frequencies from 300 - 3000 cycles. It would seem that a dynamic test should be devised as a standard of measurement to provide a more accurate yardstick of true performance.

Another negative contribution is the loudspeaker itself when subjected to high ambient or background noise. The speaker cone distorts and produces a conversion pattern quite different from its pattern in ordinary surroundings. This is again interpreted by the ear as a form of distortion.

In several units, we found it convenient to mount the loudspeaker behind the driver and facing forward. Since these were open units, the forward motion of the vehicle caused wind pressure to be developed in the speaker tending to push the cone backward. While the speaker behaved normally at standstill, as soon as a speed of 40 to 50 MPH was reached, the speaker sounded mushy and distorted. The loudspeakers were re-located and this solved the problem. This experience was graphic enough to be readily understood. When we consider that the same effect is produced by the sound pressure waves of loud noises, we can understand that a form of modulated distortion takes place and that extremely low frequencies such as 30 or 40 cycles, which are not ordinarily considered as having an appreciable effect on speech interference, we have such an effect even though it is an induced and not a direct one.

It would also be in order to provide automatic volume controls geared to ambient noise so that what is a normal audio level at low vehicular speeds will not be completely drowned out at higher noise levels and conversely when set under high noise conditions does not blast when a quieter envirement is encountered. There are, of course, several approaches to the solution of this problem such as anti-phase sampling, sampling of out of band noise, etc. Since all our tests indicate a reasonably consistant noise distribution pattern in vehicles there seems to be some merit in utilizing frequencies outside of the 300 - 3000 band for sampling purposes. In industrial applications, this analysis probably would not be valid where particular frequencies within the speech band are the prime offenders and the broad band anti-phase analysis would present a better solution.

While this discussion has been confined to fire apparatus, it is equally applicable to all large vehicles and industrial installations. A few measurements on large trailer trucks with diesel engines indicated that there is no appreciable difference between those units, concrete mixing trucks and fire engines except that the latter accentuate the problem when blowing horns or sirens. Since none of the figures contained herein show the effect of such noise makers, they can be taken as being reasonably representative of conditions generally encountered in large and also high speed vehicles.

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BOTHERANCE REJECTION WITH DOUBLE-BARRELED CHANNEL GUARD

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Summary. A number of solutions to the Land-Mobile Communications "botherance" problem are discussed. Tone coding is shown to be a practical and expedient method of rejecting botherance by the use of a continuous, tone-controlled squelch system. The requirements of such a system are given, and a design satisfying the requirements is explained. A novel method of modulating the transmitter is shown and a method of including both noise-operated and tone-operated squelch systems in the receiver in order to provide automatic channel monitoring before transmissions is discussed.

Imagine that you are the proprietor of a rifle range. Your space is limited--you can't even buy more--but as long as you have no more shooters than you have firing points, everything is all right. If you were deluged with shooters, you would do everything you could do to squeeze them in--you'd put in 2 shooters where there was one if you could. Eventually, you might stack them up and have several shooters shoot at the same target. Of course, you will exercise the best safety habits and you will be on the look-out for ways to improve your facility.

The Land Mobile Two Way Radio Industry, which we can consider as being made up of manufacturers, user groups, RETMA, and the FCC, is the proprietor of a range, too. We have three large ranges--the 25-50 mc range, the 144-174 mc range, and the 450-470 mc range. We have experienced the deluge of shooters--and we have seen them squeezed in. The General Electric Company has been pleased to be a supplier of some of the most accurate "guns" and the smallest "targets" in the business, but in spite of the advancements, we have seen the shooters stacked higher and higher on top of each other-some hitting the targets they were shooting at, and some accidentally hitting others. Being good proprietors, we (the whole industry) have, of course, been searching for new techniques to improve our range facilities.

The General Electric Company was represented on the RETMA Committee TR8 in 1954 when a list was made of possible solutions to the crowded-channel problem. Since crowding causes interference, the list of solutions was meant to solve the skip interference and "botherence" problems. The term "botherence" refers to all those extraneous and unwanted nuisance signals that originate outside one's system.

These solutions were categorized into three groups. 1) Operational, 2) Allocational 3) Technical

OPERATIONAL

Of the operational alternatives, the first was to limit transmissions to a specific time--something like selling a customer a gun but telling him that he can only shoot it during certain hours. Since there are hardly enough "game wardens" to police limited-time transmissions, the scheme becomes impractical.

Another operational technique would have been to let the users police themselves. If all of our "shooters" were given guns without rules to follow, there would soon be trouble. Some shooters would band together in clubs to protect themselves, but we would eventually find the lawmakers passing legislation to protect us from each other. Since this method is difficult to instigate, organize, and police, it has become of limited usefulness.

ALLOCATIONAL

One of the allocational methods proposed was to divide the Western Hemisphere into zones and allocate frequencies in each zone so as to minimize skip interference from other zones--like asking the shooters on one side of the pond to shoot at different ducks than the shooters from the other side. This would have required international agreement and would have upset many of the present geographical assignment plans that user groups now have. It would not have solved the "same area" type of interference problem.

The second allocational method for reducing interference was to reserve 10% of the split channels to reduce international problems. This one, of course, is very difficult to organize.

TECHNICAL

Many technical possibilities came to the minds of that RETMA group. The most obvious, of course, is to increase the number of RF channels. We are limited, at the present, by such things as oscillator stability, transmitter noise (of units in use), receiver band width, and field measuring equipment. If cost were no object, some of the present day specifications could be improved--some could not, with the art in its present state. It would mean that our "guns" would have to be much more accurate and the "targets" still smaller.

A second way of reducing interference is to limit the power-like using a smaller powder charge in the gun. Studies show that the power would have to be about 30 db lower than the power output of present equipment. This is inconsistent with the demand for "bigger guns."

Directional antennas offer a solution if the interference always came from the same direction--which it doesn't. And for the same-area mobile operation, we must presume that the mobiles will operate in more than one direction from the base

station. The use of swept antennas was also mentioned. Under this system, the antenna would sweep 360°, but would "lock-on" to the received signal for both the receive and transmit cycles. The state of the art has not advanced to the point where this system is quite practical--and wouldn't guarantee that one would lock on to only the desired signal.

Another solution that has some promise is a 10 kc offset system. The interferring channels would be set 10 kc off in order to give as much as 40 db protection, during pauses in conversation, and 10-20 db during modulation. This system would be impractical in 20 kc channel areas since the next channel would then be only 10 kc away.

The General Electric Company is experimenting with a power control system. In this case, the "target" tells a "shooter" just how big a charge to shoot in order to hit the "target". By sensing the strength of signal from the mobile station, the base station automatically adjusts its power to just reach the mobile receiver. Although General Electric has had such a system in operation for more than two years and it has shown considerable promise, we feel that it needs more study.

So we find ourselves having made our guns as accurate as is now consistent with cost. We have made our targets smaller, we've tried shooting in only one direction, we are experimenting with controlling the size of the charge, and we have been faced with various kinds of self-control and legislation. About the only thing that hasn't been mentioned yet is color coding the buckshot! This scheme was referred to, by the 1954 RETMA group, as tone signalling. Figure #1 shows some of the possible methods of using tone signalling.

One method of using this color-coded shot, is to fire a short burst of it before the main charge. This means that the target must be designed to allow only a special color to go through. (Here's where we in the electronics business have it all over the ducks--they can't "receive" shots of their choice!) This tone initiated system of Fig. 1A has been supplied by the General Electric Co. for several years, although not primarily as a means of controlling interference. One of its disadvantages is that it does not drop out if captured. Another is that it requires some manual operation by the operator to reset it.

To overcome the disadvantage of manual reset, it is possible to use a tone at the end of the transmission to perform the reset function, as shown in Fig. 1 B. This technique is something like taking 3 shots to kill the bird. True--it gets the job done but the greatest disadvantage is that it takes too much time--air time that is a priceless commodity. It also suffers from the disadvantage that it doesn't drop out if captured and that one can't be sure that the drop-out tone got out.

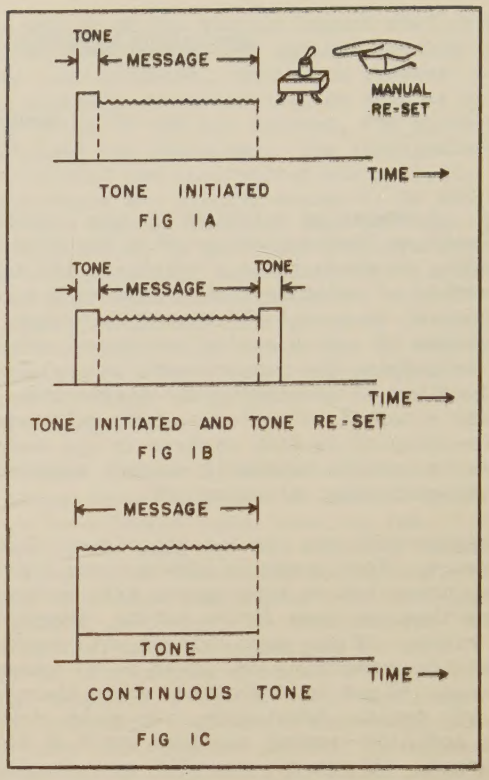

Fig. 1 - Tone squelch coding methods.

Since pulsed tone, as it applies to interference and "botherance", suffer from some disadvantages, let us examine the use of continuous tone as represented in Fig. 1C. This is something like putting two barrels on the gun and shooting them simultaneously. One doesn't shoot both barrels of a gun simultaneously, though, without exercising considerable caution. In a continuous tone system, we must be sure that it meets the following requirements:

(1) Low level so as not to bother non-users
(2) Fast opening
(3) Sensitive
(4) Stable
(5) Need provision for monitoring (safety device).

In a continuous tone-controlled squelch system, the transmitter is modulated with a low-level "background tone" throughout the transmission. A tone decoder in the receiver then responds to the transmitter's code tone and actuates the squelch circuit. We are given a choice of the tone to be used--it can be either high-frequency or low-frequency--either an "over" or "under" gun! Let us suppose that we were to use a tone of 3000 cps and that the Q of the selective device in the receiver were 50. The band width would then be

$$BW = \frac{f_o}{Q} = \frac{3000}{50} = 60 \text{ cps.}$$

If a low-frequency tone of 100 cps had been used, the BW, with a Q of 50, would have been 2

cps. This represents a noise power increase, in the high-frequency pass band, of $\frac{60}{2} = 30 = 15$ db.

Therefore, the tone at the high-frequency end of the voice band would operate at a 15 db signal-to-noise ratio disadvantage compared to the low-frequency tone.

This, in addition to the presence of voice-frequency harmonics would make it extremely susceptible to false triggering. Since the tone would be in the voice band, elaborate notch filters would be needed to keep it from being a nuisance.

We should also examine the frequency response of a high-quality land Mobile radio system to see which tone we are least likely to hear at the receiver output. Figure 2 shows the response of typical receiver audio system with consideration of the speaker response and the ear response. The heavy curve indicates that the actual reproduced level at 100 cps is 37 db lower than the level at 2000 cps. This means that the non-tone-squelch equipped user would hear less of 100 cps modulation than he would of 2000 cps for the same deviation.

Fig. #3 shows the energy distribution of audio coming off a receiver discriminator before de-emphasis. With no signal, the noise level per cycle of bandwidth is the same at 100 and 2000 cps--a surprising development since most text books would lead one to believe that the noise rises at 6 db/octave.

With signal and audio, the energy distribution is different, as the curve shows. If we begin with the normal voice energy distribution curve and modify it by the microphone, audio amplifiers, and modulator characteristics, the curve shown as a solid line of Figure 3 results. Inspection shows that the voice energy at the low-frequency end of the band is less than at the high-frequency end. Since the tone level will be about 20 db below average voice modulation, the voice will be of higher amplitude at high-frequency meaning less false triggering at the low-frequency end. All things considered, then, the low-frequency tone will be less of a nuisance to the non-equipped user sharing the same channel, it will be easier to keep out of the audio and will have a better signal-to-noise ratio, for constant Q, than a high-frequency tone.

Although it would appear that low frequencies are going to be a better choice than high-frequencies--they are more difficult to "load". Consider that the modulation index of a system deviating 10 kc with a modulating frequency of 1 kc is $m = \frac{10 \text{ kc}}{1 \text{ kc}} = 10$

If a low-frequency tone of 100 cps were used to deviate the carrier 1 kc, the modulation index is also $\frac{1 \text{ kc}}{100} = 10$

This means that if both tone and voice are present, the modulator must be capable of deviating 20 kc at 1 kc modulation. If a tone deviation of 2 kc at 300 cps had been used, the modulator must be capable of $m = 2000 + 10{,}000 = 20 + 30 = 53$ which is the equivalent of 53 kc deviation at 1 kc modulation - no small trick if we expect low distortion.

General Electric has used a novel technique to circumvent the modulator problem by injecting audio directly into the oscillator rather than into the phase modulator. Figure 4 shows a conventional crystal-oscillator circuit to the right of the broken line. The circuit to the left is of an audio generator driving a diode and this

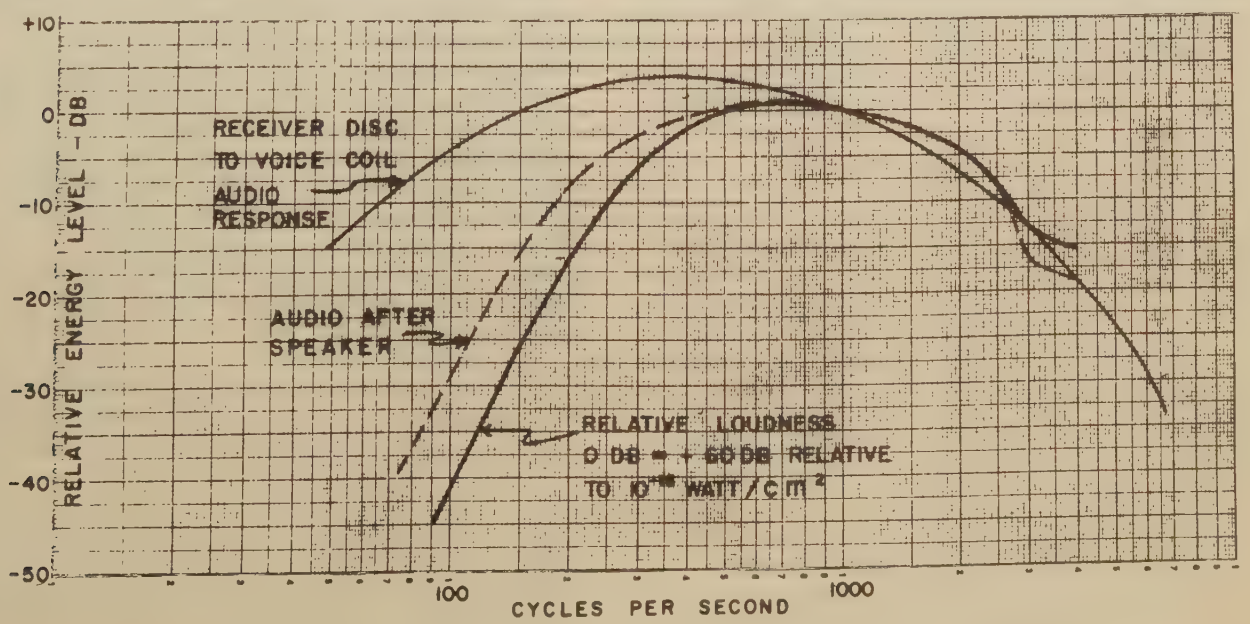

Fig. 2 - Receiver response from discriminator to listener's ear.

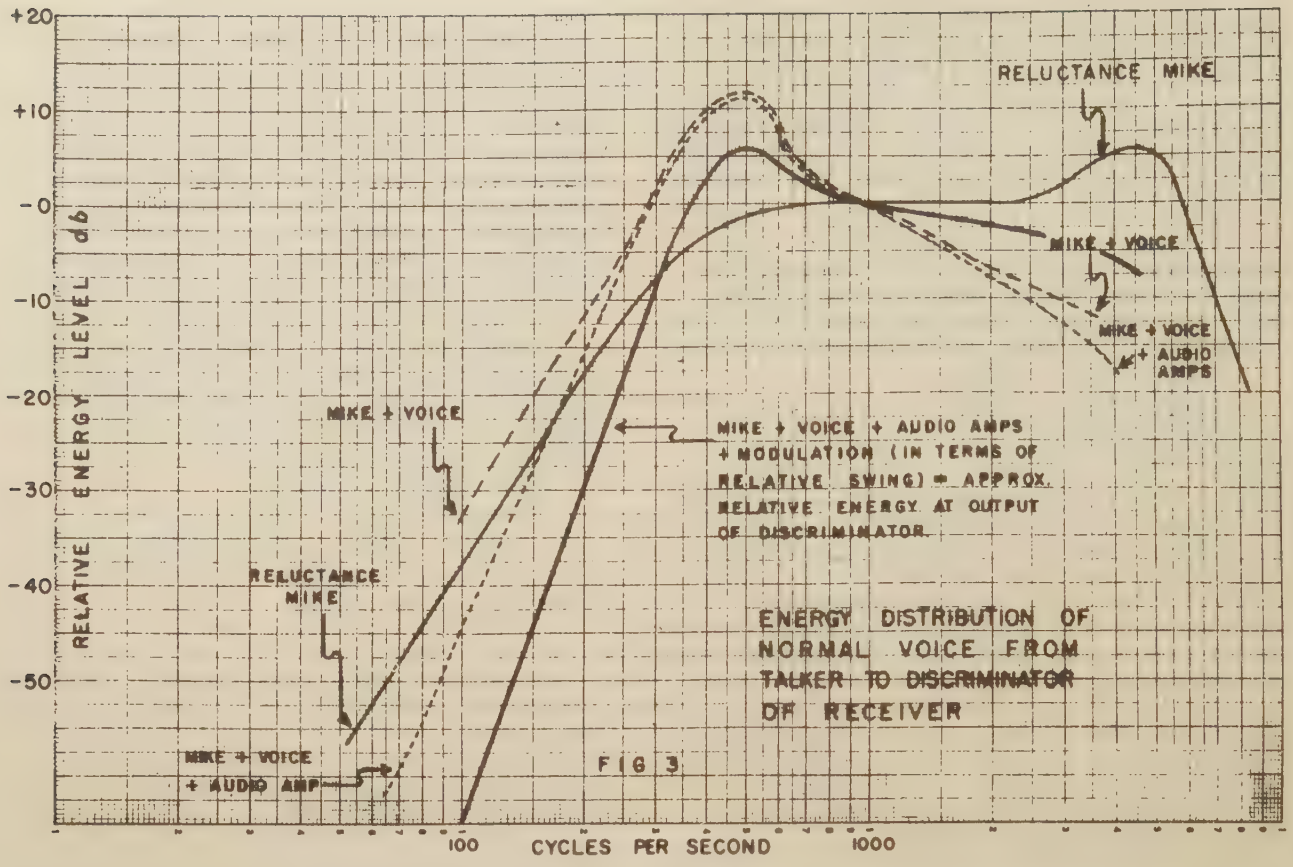

Fig. 3 - Energy distribution of normal voice from talker to discriminator of receiver.

combination is connected across the crystal through capacitor C. At first glance, it would appear that the diode merely switches capacitor C across the crystal at an audio rate, thus frequency modulating the oscillator. The diode, however, is a silicon diode which has the characteristics of appearing as a capacity at low bias

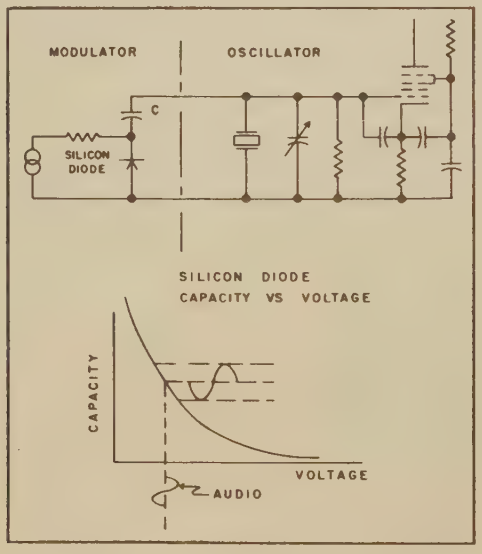

Fig. 4 - Oscillator modulation.

voltages. The curve shows that the capacity varies with bias voltage, so that if an audio voltage is superimposed upon the rectified RF bias voltage, the capacity varies at an audio rate. Now silicon has a rather steep positive temperature coefficient, so capacity C is added in series with the diode. Since the total capacity of capacitors in series is less than the smallest, capacitor C is made small with respect to the diode capacity in order to provide isolation. Proper choice of temperature coefficient of the capacitor compensates the oscillator so that it is unaffected by temperature. The beauty of this circuit is that it is capable of frequency modulation down to 0 cps at less than 5% distortion. It is important to keep the distortion low in order that the tone harmonics that appear in the voice band will be kept low. If the distortion approaches 10%, both the equipped and non-tone-squelch equipped user will suffer annoyance.

Now that we have found a high-quality method of loading our gun, let us examine the receiver squelch circuit to see how we can best take advantage of the color-coded buckshot.

Figure 5 shows a typical receiver squelch circuit. In the absence of signal, the high frequency squelch noise is amplified in the noise amplifier and rectified by the noise rectifier. This positive voltage is added to the negative

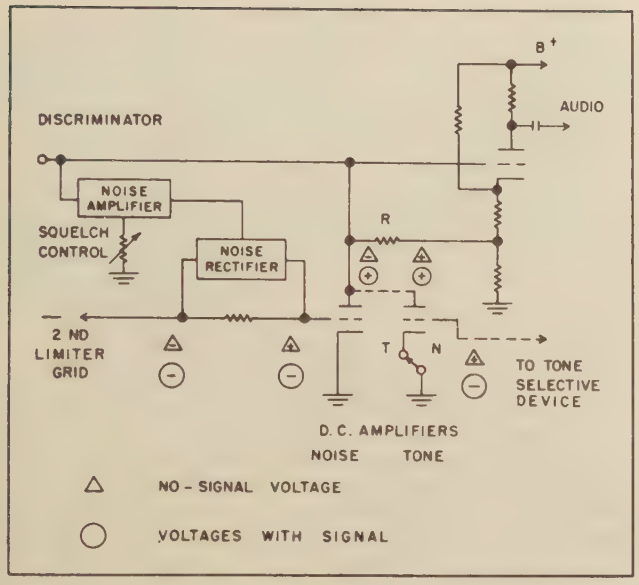

Fig. 5 - Receiver squelch circuit with "double-barreled" modification.

voltage from the 2nd limiter with the result that the voltage at the dc amplifier grid is slightly positive. When the dc amplifier conducts, the current through its plate-load resistor R causes the audio amplifier to be biased to cut-off. As the signal comes in, the 2nd limiter grid goes slightly more negative and the noise quiets, resulting in the dc amplifier grid going negative, cutting off the dc amplifier and removing the cut-off bias from the audio amplifier. So all we need do to allow audio to appear at the output is to force the dc amplifier grid negative. A simple way of doing this would have been to replace the noise amplifier-rectifier, and 2nd limiter voltage combination with a selective device connected to the discriminator. The selective device could then have switched negative dc (or rectified a signal to apply negative dc) to the dc amplifier grid to cause opening. This would have then meant that the receiver was entirely at the mercy of the tone-operated squelch and would have been deaf to all other calls. This would be particularly embarrassing inasmuch as the operator would have no provision for monitoring his channel before a transmission. A scheme such as this would be akin to a gun without a safety device - one might shoot someone without meaning to! Of course, a disabling device could be provided to tie that dc amplifier to a negative voltage source by some manual method. If the channel were busy, the message would be heard, but if it were clear, the squelch noise would come blasting through. This is something like shooting the gun into the air as a safety precaution to be sure that one doesn't injure someone! We, at General Electric, were nearly ready to release just such a system when we realized that we had not assumed our moral responsibility of providing the "safety catch" that would protect the co-channel user. (Those of you who have seen our KT-4-A tone generator will notice the empty holes in the printed board that were to be used for a rectifier system.)

What is really needed is two switches in series - one operated by the noise and one (capable of manual closure) operated by the tone - a scheme of making the target double-barreled, too! The second dc amplifier in Figure 5 is the second switch. If only one dc amplifier grid goes negative, the other still conducts to bias the audio amplifier to cut-off. When both carrier and tone are present, both grids are negative, and the receiver is "open". A switch in the tone-section cathode provides a means of disabling the tone-operated squelch but gives completely normal noise-squelch operation. This switch is actually a part of the microphone hang-up bracket meaning that when the operator lifts the microphone, he automatically exercises the courtesy of monitoring the channel. On station microphones, a key lever switch in the microphone forces the operator to go through a monitor position from "Channel Guard" to "Transmit". Imagine the case where a Mobile unit goes from a tone-coded area into a non-tone equipped area - it is now possible to operate with standard noise-operated squelch at will. Also, it should be pointed out that the noise dc amplifier grid begins going negative far before the signal is strong enough to read. The tone dc amplifier grid operates near the critical point so that when both carrier and tone are present, the receiver opens at levels that are too weak to read. Full opening takes place at a SINAD* of 5 db or less. On a General Electric low band, wide band receiver, for instance, this is the equivalent of about 0.07 microvolts! By providing both

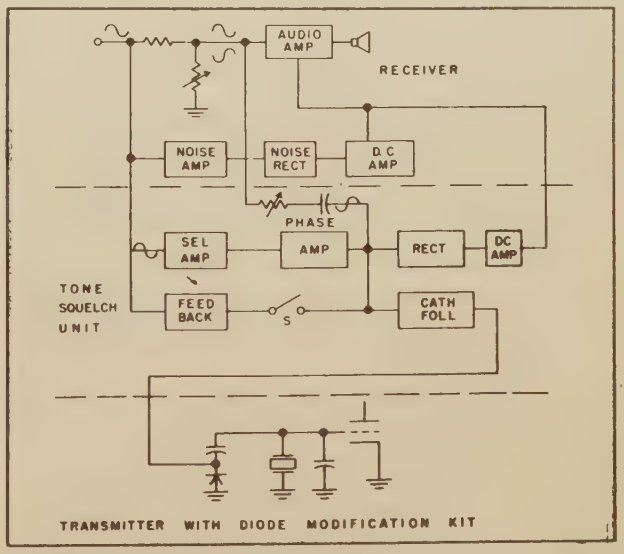

Fig. 6 - Block diagram, transmitter and receiver with tone squelch modification.

noise and tone-operated squelch, the watchman guarding the channel has a heavily-loaded Double-Barreled gun!

Figure #6 shows, in block diagram form, the technique used to add Double-Barreled Channel

* SINAD - $\frac{\text{Signal + Noise + Distortion}}{\text{Noise + Distortion}}$

Guard to General Electric Equipment. The top part of the figure is a standard receiver with its noise-operated squelch. In the center of the figure, there is a selective amplifier which is fed from the receiver discriminator. The selective amplifier output is amplified, rectified, and applied to the second dc amplifier which we have already discussed. Notice the RC combination marked PHASE. These components feed a signal which is 180° out of phase with the tone signal at the discriminator back into the audio chain. This technique results in notching out the tone from the audio section to make it unobjectionable at the output. Typical attenuations are 35 db below 2/3 rated deviation.

When the transmitter is keyed, the receiver is muted and switch S is closed. This completes a feedback path around the selective amplifier, forcing it into oscillation. The oscillator output is cathode-follower coupled to the transmitter oscillator circuit. Figure 7 is an elementary diagram showing the tone-squelch unit. As a tone receiver, the discriminator is coupled to the grid of V601. The tone is then fed to the first half of V602 and thence through the plug-in A "parallel T" network is a high-impedance to the desired frequency so that all frequencies but the desired frequency we fed back through Z601 and are cathode-coupled to the first half of V601 to reduce its gain. The desired frequency is coupled out of the first half of V602, through the second half of V602 which is a voltage amplifier with considerable gain--stabilizing feedback. In the network between halves of V602, CR603 is a voltage sensitive resistor that stabilizes the gain of the first section. Diode CR602 normally conducts so that the voltage appearing at the junction of R610 and R618 is shunted to ground through R609, thus eliminating the feedback through R603 to the input grid of V601. The output of the second half of V602 is coupled, through the DC LEVEL control to the "inside clipper" formed by CR604, CR605 and the associated components. The two diodes operate as a conventional full-wave voltage doubler biased to prevent conduction until a specified level is reached, giving protection on noise pulses and any low-frequency voice components at the network frequency. The negative output of the rectifiers is integrated by R634, and C611 to remove any tone components and is applied to the grid of V603, the dc amplifier previously described.

To convert the operation to oscillator at the network frequency, a source of keyed B+ is applied across R616 and R609. The developed voltage is sufficient to prevent conduction of diode CR602 so that there is feedback to the input grid of

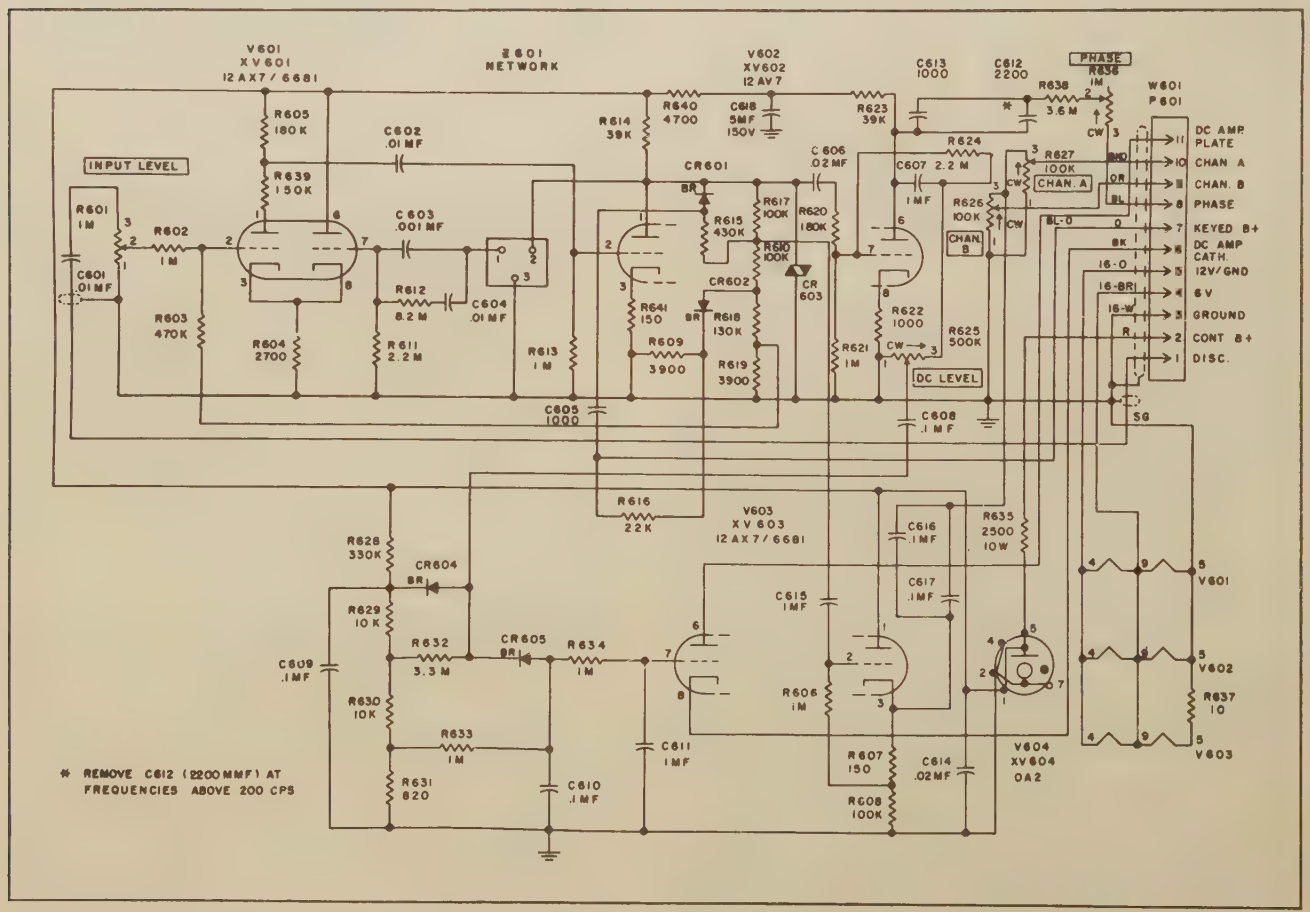

Fig. 7 - Tone squelch transmitter-receiver (4KT5A1).

V601. The feedback is controlled to give a low-distortion output. At the instant that B+ is keyed to R616, capacitor C605 charges and forces CR601 to conduct for an instant. When CR601 conducts, R615 is shunted across R617 so that the feedback is momentarily increased in order to start the oscillator in less than 25 milliseconds. The oscillator output is taken from the second half of V603, a cathode follower. Two controls, CHAN A and CHAN B, adjust the level fed to either of two transmitter oscillator circuits for two-frequency operation.

The heater connections are connected for 6/12 volt operation in order that the device may be connected to either 6 or 12 volt systems.

Now let's take stock of this double-barreled squelch. We listed some of its important requirements as being 1) low-level modulation to prevent bothering non-equipped users, 2) fast opening 3) sensitive, 4) stability, and 5) a monitoring provision. We have seen how the sensitivity and monitoring provisions have been met; now let's examine the others. It is important that there be some industry standard by which to measure these requirements in order to protect the customer and allow equipments from various manufacturers to operate in the same system. The leading Land Mobile equipment manufacturers are presently engaged in writing the RETMA Standards for continuous Tone-Controlled Squelch Systems.

The level of modulation is something of a compromise. The higher the level of modulation, the greater the level of recovered audio at the discriminator, meaning a higher signal-to-noise ratio. Also, however, high levels impose a hardship on those non-equipped users who have no filter to keep the tone signal out of their speakers. It can be demonstrated that for a given opening time (which is dictated by bandwidth, as we shall see) that the signal-to-noise ratio to produce essentially no random openings occurs at about 1 kc deviation, in systems using ± 15 kc maximum deviation. One kc also produces sufficient signal to give fast, reliable operation in the extremes of environmental and signal conditions. Where 1 kc produces a given integrated signal-to-noise ratio at the output of the selective amplifier in wide-band systems, 0.75 kc produces the same signal-to-noise ratio in narrow band systems.

We, in the Mobile industry, have had many years of experience in adjusting opening times of squelch systems. As soon as the opening time exceeds 250 milliseconds, we know that the first syllables of calls will be missed and that we will have mail baskets full of "suggestions".

We also know that if the attack time is too short, that the squelch may "flutter" on noise spikes. The time of response can then be broken into two parts--the time constant of the DC circuit, and the response time of the selective device. The DC circuit is generally designed to give about 150 milliseconds attack time, leaving 100 milliseconds for the selective device.

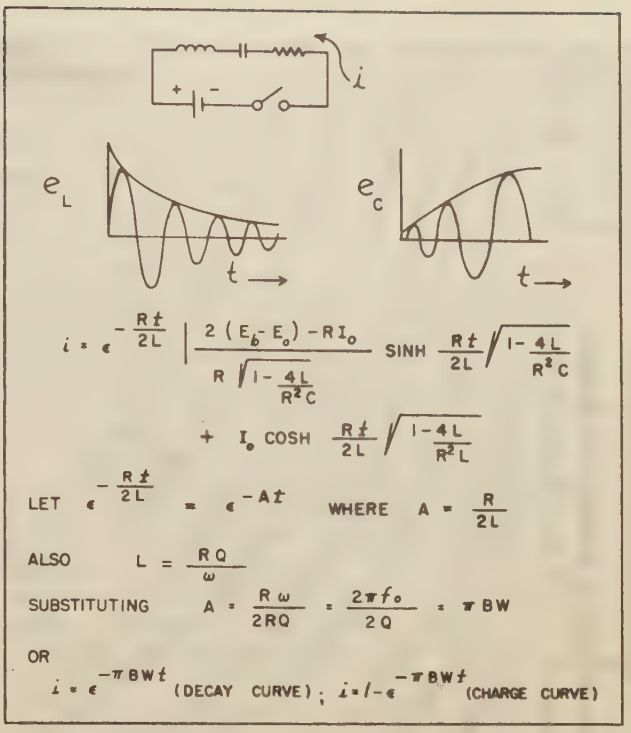
i
+
-
e_L
t
e_c
t
$i = \epsilon^{-\frac{Rt}{2L}} \left| \frac{2(E_b - E_o) - RI_o}{R\sqrt{1-\frac{4L}{R^2C}}} \right| \text{SINH} \frac{Rt}{2L}\sqrt{1-\frac{4L}{R^2C}}$
$+ I_o \text{COSH} \frac{Rt}{2L}\sqrt{1-\frac{4L}{R^2L}}$
LET $\epsilon^{-\frac{Rt}{2L}} = \epsilon^{-At}$ WHERE $A = \frac{R}{2L}$
ALSO $L = \frac{RQ}{\omega}$
SUBSTITUTING $A = \frac{R\omega}{2RQ} = \frac{2\pi f_o}{2Q} = \pi BW$
OR
$i = \epsilon^{-\pi BWt}$ (DECAY CURVE); $i = 1 - \epsilon^{-\pi BWt}$ (CHARGE CURVE)

Fig. 8 - Single-tuned circuit time response.

The selective amplifier which has been described, has the response of a single-tuned circuit. To find the time of response of a single-tuned circuit, it can be treated as a circuit as shown in Figure 8. When the switch is closed, there will be a damped oscillation whose frequency is equal to $\frac{1}{2\pi\sqrt{LC}}$. The curves show the familiar decay and charge curves of voltage across the inductance and capacity. For the DC case, the current can be expressed by the equation shown. The term $e^{-\frac{Rt}{2L}}$ describes the shape of the voltage appearing across the inductance. Performing the substitution shown in Figure 7, gives the current in terms of the bandwidth of the system. When $T = \frac{1}{\pi BW}$, the voltage across the capacitor will have increased to $1 - e^{-1}$ or 63% of full voltage. For various Q's, therefore, the time required for an applied sinusoidal voltage to build up to the 63% (4db) points can be plotted. By using the universal selectivity curves for a single-tuned circuit, one can calculate the bandwidth at points further down on the selectivity curve. The time for each of these "margins" has been plotted as a family of curves for various Q's in Figure 9A.

Now let us propose some frequency spacings and tolerances in order to see what part they play in the overall picture. Figure 10 shows spacings and of 10%, 5%, and 3% with stabilities of 1% and 0.25%. For convenience, the desired frequency has been chosen as 100 cps. The 1/2 bandwidths that can be used are then defined for each set of conditions. The permissible band-

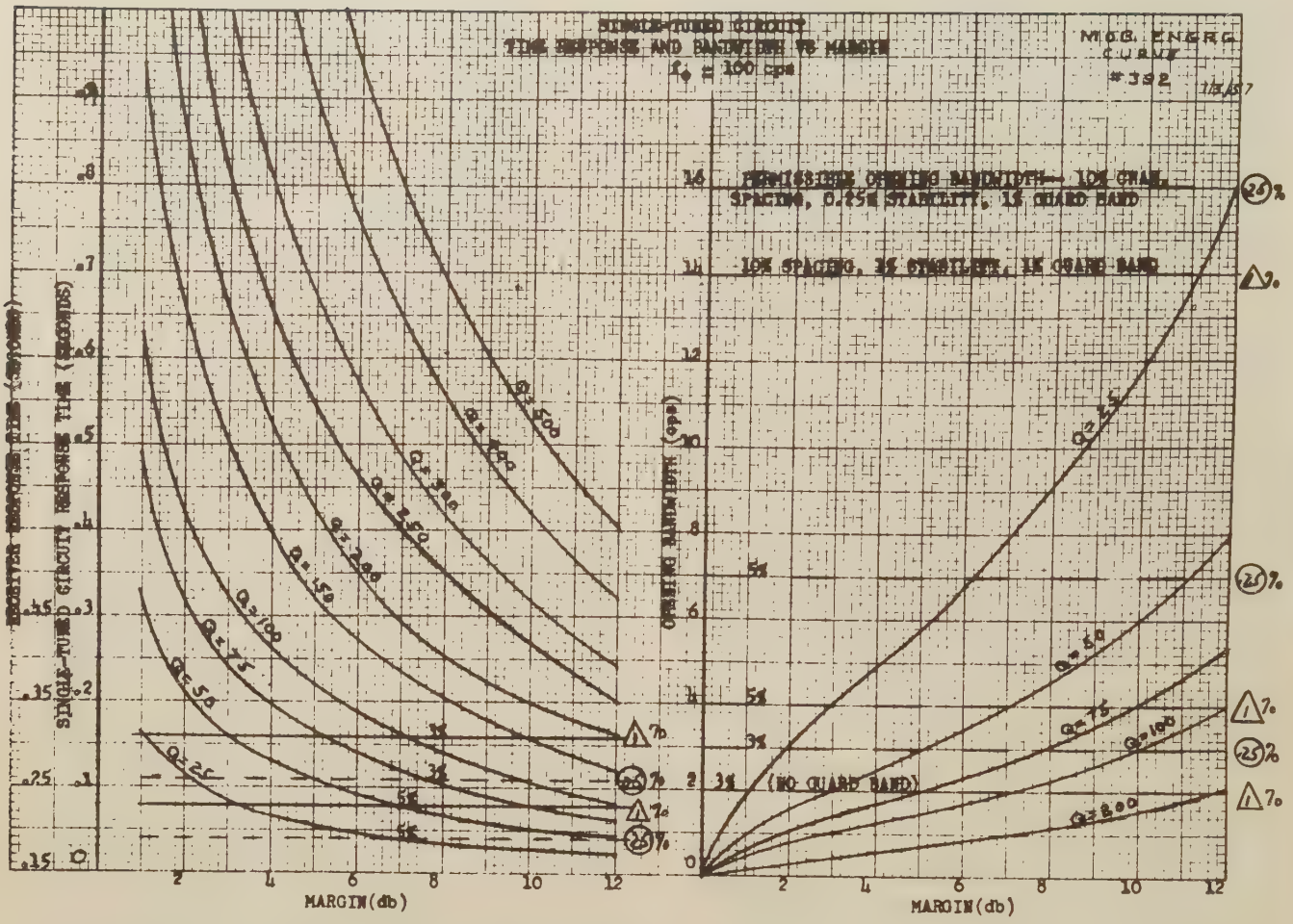
SINGLE-TUNED CIRCUIT
TIME RESPONSE AND BANDWIDTH VS MARGIN
f_o = 100 cps
MOG ENERG CURVE #392
SINGLE-TUNED CIRCUIT RESPONSE TIME (SECONDS)
OPERATING BANDWIDTH (cps)
MARGIN(db)
MARGIN(db)
PERMISSIBLE OPERATING BANDWIDTH — 10% CHAN. SPACING, 0.25% STABILITY, 1% GUARD BAND
10% SPACING, 3% STABILITY, 1% GUARD BAND
(NO GUARD BAND)

Fig. 9

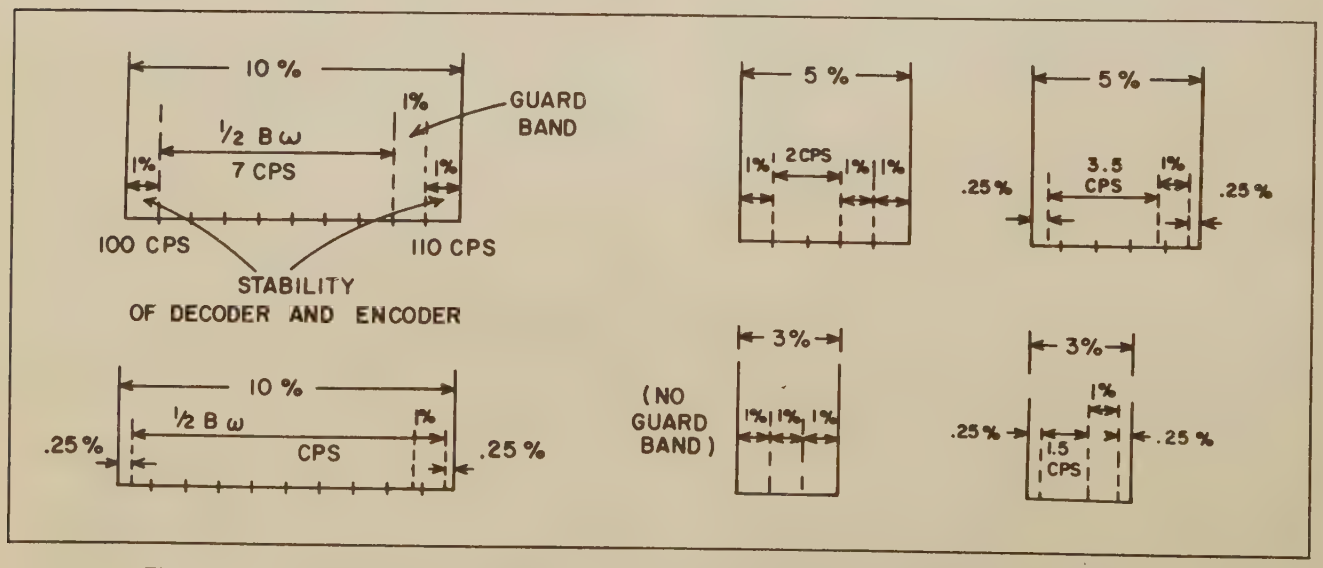

Fig. 10 - Permissible half-bandwidth based upon tone channel spacing and stability.

widths are shown as horizontal lines in Figure 9B. These permissible bandwidths have also been translated over to the time domain of Figure 9A, by using the formula $T = \frac{1}{BW}$.

In order to stay within the bandwidths allowed for each spacing and stability, one must operate above the horizontal line for a given condition described in Figure 8A. For example, with a Q of 50 and a margin of 10 db, if the spacing were 10% with a stability of 1%, the unloaded response time of the selective device would be 70 milliseconds and the overall response time would be 230 milliseconds. Operating above the 3% spacing curves then becomes incompatible with the opening-time requirement of 250 milliseconds. This leads us to the conclusion that about 5% is the minimum spacing that can be tolerated. With 5% spacing a stability of 1% then allows adequate bandwidth for 250 milliseconds response time.

It is important to note that the above analysis holds only for those devices which maintain constant Q from the time when t - 0 until a stable operating point is reached. Devices that operate by virtue of piezo-electric effect and most electro-mechanical devices start with very high Q's and then stabilize at lower Q's, depending upon the external conditions.

From the above discussion it can be seen that the Q, the margin, or the bandwidth of the responsive device is not arbitrary, but rather sharply defined by the receiver opening time required. Discussions in the RETMA Standards meetings have ninged around these factors, but standards are not yet finalized. General Electric is providing Channel Guard equipment designed to meet the 250 milliseconds response criterion. On this basis, tone frequencies are spaced 10.9% apart although, as the curves show, the channels could be split to 5.45% spacing when the need arises.

This has been the story, then of "double-barreled" Channel Guard. To recapitulate, we have analyzed some of the Operational, Technical, and Allocational methods by which "Botherance can be minimized. Tone signalling has been shown, to be a practical and expedient method of solving the problem. It was shown that the use of a continuous--tone squelch-controlled system had advantages over a pulsed tone system. The choice of loading the "double-barreled" gun with high-frequency or low-frequency tone was discussed and low-frequency tones were shown to have an advantage. Methods of actually accomplishing the codingand decoding were shown, and then reasons for some of the design parameters were discussed. These are the sorts of things that we "range" proprietors must keep in mind when we design, specify, maintain, and administer our "ranges". This is how Progress is designed into Products.

1. Federal Telephone and Radio Corporation "References Data for Radio Engineers", Third Edition, American Book - Knickerbocker Press, Inc. (Feb., 1953, P. 104)

CURRENT PROCEDURES IN RADIO FREQUENCY ALLOCATION

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The purpose of this paper is to discuss some of the problems of the United States in the field of frequency spectrum management and the role of the Federal Communications Commission in this field. Before discussing frequency allocation problems currently before the FCC, it will be helpful to describe the national organization for frequency management activities and also the international organization for this same purpose.

Some of the letters which we receive indicate that the general public has an impression the FCC has sole authority in the field of radiocommunications and spectrum management. As a matter of fact, such authority is divided, owing to the jurisdictional setup established by the Communications Act of 1934 and its predecessor, the Radio Act of 1927. When Congress in 1927 decided to utilize the Interstate Commerce clause of the Constitution to extend Federal jurisdiction over radio and thereby solve some very pressing current problems, it was faced with the constitutional fact that the President is Commander-in-Chief of the Armed Forces. Therefore, to insert an independent Federal agency into the chain of command between the President and the Armed Forces, insofar as telecommunications matters are concerned, posed a very difficult problem. To solve this problem Congress decided that the President should have complete authority to assign frequencies to radio stations belonging to and operated by the United States. On the other hand, jurisdiction over all radio operations by state and local governments and by all private and commercial users was vested in the Federal Communications Commission. From the frequency management standpoint, the important point here is that both the President and the FCC have authority to assign any frequency in the radio spectrum without regard to what the other party already may have done or plans to do. Since there is only one spectrum, but two authorities with concurrent jurisdiction, it is obvious that great care must be exercised to avoid harmful interference between stations operated under the two authorities. The President exercises his assignment authority through the Interdepartment Radio Advisory Committee (IRAC), which was established in 1922 as an interagency body and as such has perhaps the longest continuing existence of any inter-agency committee in Washington. A few years ago under an executive order, the actions of the IRAC were made subject to general supervision and policy control by the Director of the Office of Defense Mobilization, who maintains a small telecommunications policy staff charged with the general responsibility of coordinating the uses of radio by the various agencies of the Federal government, hereinafter referred to as government uses.

Over the years a complex mechanism has grown up for the coordination of frequency allocation and assignment matters between the FCC and the IRAC and, more recently, the ODM. In 1940 an agreement was entered into between the FCC and the IRAC whereby each agreed to consult the other before assigning frequencies. This "hand-holding" agreement continues in effect to the present day. The key word here is "consult". In the course of carrying out the agreement, several devices are used. For example, some of the frequency bands above 25 Mc are, by agreement, allocated exclusively for non-Government use, others exclusively for Government use, and still other parts are allocated for joint use by both Government and non-Government users. With respect to space which is allocated exclusively for use by one or the other of the two groups, coordination of individual radio station assignments is generally not necessary. With respect to joint bands, however, each individual assignment is usually coordinated in advance in order to determine whether or not harmful interference would be caused to pre-existing assignments of the other. Even here, however, there are exceptions. For example, when a joint band is used for purposes such as marine radar navigation, experience has shown that it is not necessary to coordinate individual assignments.

Below 25 Mc there are no exclusive Government or non-Government bands provided in the table of allocations. Instead, assignments are intermixed and, because of the greater possibility of interference, individual assignments are generally subject to FCC-IRAC coordination. There are a few bands, however, which are treated as though they were exclusive. For example, the standard (AM) broadcast band and the bands allocated to the aeronautical mobile service. With respect to the latter, there is a subdivision between Aeronautical Route and Off-Route allocations. The FCC exercises exclusively the assignment jurisdiction over Route bands with a view toward meeting the civil aeronautical requirements in the aeronautical mobile service. The IRAC exercises similar jurisdiction over the off-route bands to provide for the Government aeronautical needs.

You may ask why bands below 25 Mc are not sub-allocated between Government and non-Government, whereas bands above 25 Mc are so sub-allocated. In part, the reason is historical, but there are additional reasons too. Principally, frequencies below 25 Mc, because of radio propagation characteristics, are essentially international in character and between

4 Mc and 25 Mc are allocated internationally to various radio services. The services involved are broadcasting, the fixed service, the amateur service, the aeronautical mobile service and the maritime mobile service. Since the bands are international in character, and since pre-existing assignments made by other countries must be taken into account before we can make an assignment, little useful purpose would be served by attempting to break the bands down between Government and non-Government and then to superimpose such an arrangement on the pre-existing international allocation. Although the bands above 25 Mc, up to 10,500 Mc, also are allocated internationally to various services, the service and interference ranges are normally short, making it possible to sub-allocate or to derogate from the international allocation as a matter of national convenience. This is permitted by international regulations, so long as it can be done without causing harmful interference to the services which are provided for internationally. Thus special consideration must be given to border assignments and to the bands which provide for internationally used mobile and navigational services.

From what has been said so far, two conclusions are evident:

(1) If the FCC desires to undertake a reallocation of the spectrum, it must take into account pre-existing international agreements which have allocated the spectrum broadly for various types of uses. This is most particularly the case with respect to frequencies below 25 Mc, and to a substantial degree is true also for frequencies above 25 Mc.

(2) With respect to frequencies above 25 Mc, the FCC, since it does not exercise exclusive jurisdiction over the spectrum, has available for consideration only bands which by agreement are available exclusively for non-Government use and, to a limited degree, joint bands for Government and non-Government users. The space allocated by agreement exclusively to Government use is not subject to FCC jurisdiction except by negotiation with the Executive Branch to modify the Government/non-Government agreements. These two conclusions greatly restrict the scope of any general reallocation proceeding which parties in interest might wish to have the FCC undertake.

Let us turn briefly now to the mechanism and procedures for international allocation. The Secretary of State is responsible to the President for the conduct of foreign affairs. Since there are extensive and detailed international agreements in the field of telecommunications, such matters are of considerable interest to the Department of State. At the international level then we have what amounts to a triangle, with the Department of State at the apex having final authority for making national policy, supported jointly at the base by the FCC and its licensees on one side and the ODM and the Government users of radio on the other.

In the carrying out of its responsibilities the Department of State has established still another inter-agency group known as the Telecommunications Coordinating Committee. It is an informal voluntary group created in 1946 by an exchange of letters between the Secretary of State and the Heads of four other Federal departments and the FCC. The purpose of this move was to create a body to consider telecommunications policy questions and thus to fill for the post-war period a gap left by the demise of the Board of War Communications. The Committee is composed of one representative of the Departments of State, Treasury, Commerce and the FCC and the Departments of the Army, Navy and Air Force. TCC representatives are designated by the Heads of each agency; they are supposed to be persons of Under-Secretary or Assistant Secretary level for the non-military agencies and the chief communications officers of the Armed Services. The Committee, as a matter of practice, includes in its meetings and in the composition of any working committees representatives of any non-member agencies having a special interest in the work in hand.

One of the tasks of the TCC is to assist the Department of State in preparing the U.S. position for international telecommunication conferences. Such a conference, dealing with radio matters, has been scheduled by the International Telecommunication Union to take place sometime during 1959. It is called an Administrative Radio Conference[1,2,3] and its task will be to review and revise the basic international regulations relating to the use of radio which were adopted by the Atlantic City Convention in 1947[4]. This is the first such conference to be held since that time. Since there has been substantial progress in the techniques and uses of radio since 1947, a comprehensive review of the international regulations appears to be necessary. Accordingly, the State Department has organized Government-Industry preparatory committees to review the various parts of the Radio Regulations and to recommend a U.S. position to take to the Conference. To indicate the magnitude of the job, it is expected that the Conference itself will run for from 5 to 6 months, and that most of the 96 countries, members of the International Telecommunication Union, will have representatives present.

The State Department's organization of preparatory work for the 1959 Administrative Radio Conference is as follows: A group of five committees has been set up, consisting of an Executive Committee (Committee No. 1) and four technical committees. The principal work is carried on by the four technical committees. Committee II is assigned the task of considering the Organizational Regulations; Committee III is to review frequency allocations for the entire spectrum beginning at 10 kc and up as high as we find it necessary to go; Committee IV

is to review technical questions such as emission designators, frequency tolerances, harmonics, etc.; while Committee V reviews the operating regulations, including call signs, distress frequencies, standard frequency transmissions, etc. Each of these four technical committees, in turn, has subcommittees working on specific jobs. Reports and recommendations flow from the subcommittees to their parent main committees, and upon adoption by a main committee are transmitted to the Executive Committee. Matters approved in the Executive Committee then are subject to further interagency coordination via the mechanism of the Telecommunications Coordinating Committee. This is a long chain of command and it is fortunate indeed that the U.S. already has started its preparatory work for the 1959 Conference, even though the Conference is over two years away.

Although the conduct and management of telecommunications affairs at the international level seems considerably removed from the scope of activity of most of us, it is well to emphasize the importance to the United States of actions taken at this level. To a surprising degree, the scope of authority at the national level is controlled by what has been agreed at the international level. The opening of new uses of radio and the expansion of old uses are both heavily influenced by actions taken at international level.

For example, let us consider Forward Propagation by Ionospheric Scatter. This is a new technique which was not known at the time that the Atlantic City Radio Regulations were adopted in 1947. Present estimates of the useful frequency range for ionospheric scatter is 30 to 60 Mc. As far as the treaty is concerned, we are fortunate in this hemisphere because most of the space is available for use by the fixed service as well as other services, and we can reach a national decision based upon the relative needs for ionospheric scatter and the presently used services in this frequency range. This is not true in the European region, where frequencies above 41 Mc are available exclusively for broadcasting and are so used. Thus, in the European region, about two-thirds of the spectrum useful for this purpose is unavailable except on a treaty derogation basis. This will have a considerable influence on the ability to use ionospheric scatter in the European region.

The State Department has invited members of industry having an interest in the international Radio Regulations to participate in the work of its preparatory committees, so that the best possible United States position can be formulated. It is urged that all of you consider this matter and participate to the extent to which you have a real interest, either directly or through your trade association representatives who may be already participating in the work. A broad base of representation in this work seems essential to the preparation of a complete and forward looking position which truly reflects the national interest of the United States and its traditional role of leadership in telecommunication affairs.

Let us now talk specifically about frequency allocations. A very important point in our consideration of frequency allocations is that all of the spectrum presently known to be useful for any purpose already has been allocated to one or more services or groups of users. From this it follows that a new use of radio or an expansion of an existing use in that frequency range can occur only at the expense of someone else. Since most users of radio tend to put their own particular use high on the priority list, it is easy to see that changes cannot be had simple for the asking. There is no large reserve of unused spectrum space into which one can reach upon request and produce the desired space.

The next point is the motivation for a reallocation; that is, the reasons which can be advanced in justification of a proposal. In this connection, it is necessary to examine a proposal's impact on the persons to whom the part of the spectrum wished already is allocated. Inevitably, the greater the adverse effect on existing users, the more convincing must be the arguments which are advanced by the proponents of change. Particularly in the case of parts of the spectrum which are heavily occupied, this can be a substantial burden to carry, since no change can be made in favor of new users except by taking the space away from existing users at considerable economic and other inconvenience and hardship. All of this means simply that if one seeks a major reallocation of the spectrum, one should have very substantial reasons to justify it.

One reason for a major reallocation might be rapid technical developments. For example, there was a technical break-through in this country during World War II, opening up large amounts of spectrum space above 30 Mc for practical use. In consequence, there was a major reallocation proceeding in 1944 and 1945, the results of which were included to the extent necessary in the Atlantic City Convention in 1947, and which has set the general pattern of domestic allocations for frequencies above 30 Mc down to the present day.

Another reason for a major reallocation might be major shifts in radio usage by the public at large. An example might be a very substantial expanded demand by industry for use of land mobile or vehicular communication. So far, the expansion which has in fact taken place has been within the framework of existing allocations. To the extent that the existing framework cannot stand the strain of further expansion, there will be requests for expansion at the expense of other services. Actually one of the land mobile user groups already has petitioned for reallocation of TV Channel 2

to delete its availability from television broadcasting and substitute land mobile users instead. Similarly, there have been suggestions and petitions filed for reallocation of FM broadcast band in whole or in part for the same purpose. The FCC has been attempting to accommodate expanding land mobile uses by making more efficient utilization of the spectrum space already allocated for that purpose instead of turning over new space at the expense of other user groups.

Another point to be considered in connection with reallocation proceedings is the timing. Among other things involved here is the interrelation of allocations actions taken at the national level and the international level. Involved here is the question of whether or not it would be appropriate for the FCC to undertake a major reallocation proceeding at this time in view of the fact that the 1959 World Administrative Radio Conference of the ITU is only some two years away. Subsequent to that conference and depending upon its outcome, major changes in the allocation structure may result, although this is not necessarily the case. The point is that if we modify allocations in this country now, we may find that some two or three years from now we will be obligated to do much of it over again, with resulting dual hardship on persons who are displaced during the course of such proceedings. A practical approach to this matter is for the FCC to undertake a very careful and detailed review of allocations prior to the 1959 Conference, but to avoid major displacements pending its outcome.

All of this leads toward the conclusion that the public interest is in most instances best served by following a policy of gradualism or evolution in the allocation of frequencies, as distinguished from a policy of rapid change by what might be termed revolution. One is led to this conclusion, among other things, by the multi-billion dollar investment which the U.S. public has in communication facilities which are dependent for their continued operation upon the present pattern of allocations. Much of this equipment is in the hands of the public directly, but much of it also represents taxpayers' dollars in the hands of the military and of our military allies and other federal and local Government agencies who are large-scale users of radio for many purposes.

In advocating a policy of gradualism with respect to allocation changes, one should distinguish this sharply from the duty of the Commission to review activity throughout the spectrum periodically for the purpose of finding out where the next "gradual change", if any, appears to be most appropriate. Thus, the Commission well might undertake a general review of a considerable block of spectrum space, and, after several thousand pages of testimony and hundreds of exhibits, conclude that the public interest would best be served by leaving the allocations largely in status quo. This may seem to some to be a cumbersome, time-consuming and expensive process, but it is the traditional method used by federal agencies to assure observance of the democratic process. Moreover, the Commission is accountable to the courts if it acts in an arbitrary or capricious manner and is accountable generally to the Congress for its trusteeship in the general field of telecommunications regulation.

Assuming now that the Commission has decided to institute a reallocation proceeding, what are some of the problems encountered during the course of such a proceeding? If it is a limited proceeding, the Commission, in order to expedite the course of the proceeding, generally will specify the issues with some particularity. This tends to give some guidance and direction to the proceeding. If it is a wide-open proceeding, the parties tend to have more latitude in deciding what type of evidence they will introduce. This latter situation is typical of an exploratory allocation proceeding where the FCC does not already have a large amount of information on the proposed uses, requirements and justifications.

A principle to bear in mind in any reallocation proceeding is that, in general, the group which wishes to displace existing users bears the burden of proof. If you want someone else's space, you should be prepared to show why you need it worse than he does, and how the public interest would be served by upsetting the status quo. Perhaps you could show that he has more space than he is using, even though he has had many years to fill up his channels. Your adversary can't dispute facts, but can, of course, claim this is temporary, he'll use it tomorrow. Perhaps you can show that technical developments make it feasible for him to do anything he is now doing in half the spectrum space, and that you could profitably use the space he no longer needs. Alternatively, he may be able to show the same about you.

Another point is not to rest your case on a simple declaration of the importance of your own activity to the national security, welfare or economy. This is important, but in these days when almost everyone is eligible to use some spectrum space for some purposes, it is perhaps more important to attempt the hard technical job of showing <u>how many</u> frequencies you need and <u>where</u> in the spectrum they should be located.

A further point to bear in mind is if you do find a hole in the spectrum, or if new techniques such as split-channel operation are developed, it does not necessarily follow that you should be the beneficiary of your own ingenuity. Perhaps we have had higher priority requirements, unsatisfied for a long while, which should be satisfied first. Ultimately, it is the public interest which must decide where and how changes in spectrum usage should be made.

Another matter to be considered is that the FCC does not exercise jurisdiction over receiver design. Hence, taking into account the existing uses of the spectrum, we are to a degree compelled to chart a course which matches the self-interest of the majority of the users of the spectrum with the regulatory course which we desire to pursue. Special care must be taken in connection with allocation changes involving the broadcasting bands due to the large investments in receivers in the hands of the general public, the fact that such investments are not amortized as in business, and the difficulty of explaining the reasons for allocation changes to the public. Such changes generally must be programmed to occur on a long-range evolutionary basis in order to allow reasonable enjoyment of the public's investment.

Turning now to more specific matters currently before the Commission, some months ago it announced a general investigatory proceeding to determine the long-range requirements for space in part of the spectrum, above 890 Mc (FCC Docket No. 11866). It is expected that a hearing running approximately 30 hearing days will start on May 20. Filings to date indicate that approximately 70 parties desire to present more than 200 witnesses during the course of this hearing. Involved in the hearing are such questions as the amount of space which should be allocated for fixed point-to-point operations and how this space should be divided between common carrier and private users; provisions for private television inter-city relay circuits; accommodation of radio astronomy requirements; technical standards which should be adopted by the Commission to govern equipment authorized to be operated in this part of the spectrum, with particular reference to equipment standards for the fixed service; and, in general, the extent of the various demands for space in this part of the spectrum and the public interest justification for them.

One of the more unusual allocation problems presently facing the Commission has to do with the subject of radio astronomy. The problem here is not to provide spectrum space in which Commission licensees would transmit but rather to provide spectrum space wherein man-made transmissions would be excluded so that natural interstellar radiation may be received. The band 1400-1427 Mc, which is of particular interest because of the radiation from interstellar hydrogen, happens to fall in the band 1300-1660 Mc, which is allocated in our region of the world for the exclusive use of the aeronautical radionavigation service, to be a part of a so-called "common system" of air navigation and traffic control. Unfortunately the laws of physics would have to be amended to change the frequency of the hydrogen line, and it is not a simple matter to find a new home in the spectrum for the aeronautical radio navigation service. This problem can be answered only in terms of the public interest, and is now the subject of a rule-making proceeding initiated by the Commission. This is another instance where the need for unique frequency requirements may demand the more drastic or revolutionary approach to solve the problem.

Still another current problem involves tropospheric scatter. Although the Commission already has outstanding an exploratory proceeding on this specialized subject, it will doubtless enter into the hearing on allocations above 890 Mc. By tropospheric scatter I refer to the use of frequencies in the UHF or SHF parts of the spectrum for circuits extending over distances up to 300 miles or so. By utilizing extremely weak fields at the point of reception and extremely high power at the point of transmission it is possible, as most of you know, to receive an intelligible signal over these distances and this may be of fairly wide bandwidth, suitable for a multitude of telephone channels or even for television at the shorter distances.

Two weeks ago the Commission announced that developments require a new evaluation of spectrum allocations between 25 and 890 Mc (FCC Docket No. 11997). Citing the rapid growth of radio, the increasing demands by both existing and potential users for more spectrum space, and technical developments in electronics during recent years, the Commission decided to re-examine its basic frequency allocation policies in the light of present and future needs. Since such an overall review has not been conducted since 1944-45, the Commission decided to institute an inquiry of a legislative fact-finding type to obtain data and information which would help it make determinations in connection with the future allocation of frequencies to the many non-Government services operating between 25 and 890 Mc. There are a large number of services presently allocated space in this part of the spectrum. Included are FM broadcasting and TV broadcasting, domestic and international fixed public, maritime mobile, aeronautical mobile, land mobile, and aeronautical radio navigation. There are also two frequencies set aside for industrial, scientific and medical use.

The inquiry contemplates a review of the present allocation of frequencies in the light of the technological progress which has been made since the last review, to determine whether a more efficient utilization can be made; to evaluate the long-range requirements of existing and potential users; to obtain data as to the feasibility of applying known and potential techniques and methods relating to efficient utilization of spectrum space; to evaluate what system or systems of frequency allocation for the future would best serve the public interest; to obtain knowledge of possible conflicts between the requirements of non-Government radio services and the space allocated to Government users; to consider long-range plans for the future use of the radio spectrum; to determine the impact, economic and otherwise, upon present users of

the spectrum and the general public if desirable changes are made; and, finally, to assist the Commission in formulating its position with regard to the preparation of a United States position for the 1959 International Radio Conference. This legislative fact-finding proceeding may result eventually in several new specific rule-making proceedings based upon the facts elicited during the course of the proceeding.

In addition to this general allocation review, the Commission simultaneously announced specific rule-making for the land mobile services designed to improve present utilization of land mobile service frequencies. Some of you may recall that last fall the Commission decided to reduce the separation between assignable channels for the land mobile service in the frequency band 152-162 Mc (FCC Docket No. 11253). The presently used channel separation is 60 kc. The new channel separation will be 30 kc with special provisions for 15 kc separation in appropriate instances. It is technically feasible to achieve this reduction in separation provided certain technical standards are modified. In that action, the Commission did not decide who should be the beneficiary of the new "split channels" thus created. It is this latter point to which the Commission's action of two weeks ago was directed. The objectives of these rule making procedures are briefly stated in FCC Public Notice No. 43703 as follows:

"The proposals are intended, primarily, to implement the Commission's Report and Order of Sept. 19, 1956 (Docket 11253) establishing a basic policy for reducing separations between presently assignable frequencies in the 152-162 Mc band. They are also designed to provide additional frequencies through modified channel spacing and assignment methods in the 26.96-27.23, 27.23-27.28, 162-174 and 450-470 Mc bands, with operation in the latter regularized in most services, and to promote greater and more equitable utilization of these frequencies.

"In this undertaking, the Commission proposes the establishment of a number of new radio services and the deletion of others. The new services would be a Local Government Radio Service, an Interstate Highway Radio Service, a Manufacturers Radio Service, and a Business Radio Service. The latter would result from combining the present Special Industrial Radio Service, the Low Power Industrial Radio Service and the elements of the Citizens Radio Service. The Power Radio Service would become the Utilities Radio Service.

"Interested persons are cautioned that a reading of the specific amendments is essential to a complete understanding of the over-all proposals. These amendments are set forth in Notices of Proposed Rule Making covering the particular rule parts affected."

A new philosophy involved in the proposals is that of multiple eligibility. By this it is meant that service groups with high priority claims on the spectrum can, in addition to using the frequencies which have been allocated exclusively for their use, also use other frequencies on a shared basis with other groups of users. Among other important things to be decided in taking advantage of split channels is whether the existing occupants will be asked to move over in a block if they are not to be the beneficiary of all of the splits or whether new services should be interspersed with them. This decision, in the final analysis, depends primarily upon the desires of the user groups affected, because inevitably any moving over to maintain a single continuous block involves the expense of changing frequency for those people who are on the affected channels. This disadvantage must be weighed against the desirability of keeping like users together in a single block of frequencies. This promotes flexibility in assignments and makes it possible for industry advisory groups to take adjacent channel problems into account more easily than is possible if the adjacent channel user is not a member of the industry group involved.

It is not possible here to go into sufficient detail to answer all of the questions which may arise about these proposals. It is recommended very strongly that you consult the Commission proposals concerning the services in which you are interested. They may be found in a series of FCC Dockets numbered as follows:

11959 - Part 2, Reallocation of fixed, land mobile, maritime mobile between 25 and 470 mc.

11989 - Parts 2, 7, 8, Maritime Mobile Service 157.3 - 162 Mc.

11990 - Part 10, Public Safety.

11991 - Part 11, Industrial.

11992 - Part 16, Land Transportation 152-162 Mc.

11993 - Part 16, Land Transportation 27 & 450-460 Mc.

11994 - Part 19, Citizens Radio Service.

11995 - Part 21, Domestic Public.

References

1. F.C.de Wolf, "The ITU and Global Communications," Trans. IRE-PGCS.,P.18; Nov., 1954.

2. P.D.Miles, "International Radio Frequency Management," Trans. IRE-PGCS.,p.22; Nov., 1954

3. E.W.Allen, "Organization and Functions of the CCIR," Trans. IRE-PGCS.,p.26; Nov., 1954.

4. "Final Acts of the International Telecommunications and Radio Conferences, Atlantic City, 1947"; International Telecommunication Union, Geneva, Switzerland.

A METHOD OF SIGNALLING BETWEEN A VEHICLE AND AN AUTOMATIC TELEPHONE EXCHANGE

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In order to transmit standard automatic telephone ringing and dialing signals over a radio system where the signal may drop out for periods of over 100 milliseconds, a system using long tone pulses has been built.

Introduction

Two-way mobile radio services have been expanding for a wide variety of users, including: trucking firms, repair and service businesses, contractors, doctors and veterinarians and industrial concerns such as petroleum, etc. Many such users are finding it advantageous to be able to connect into common carrier telephone facilities.

Many telephone companies, both Bell and independents, are already providing mobile services in various parts of the country. But since most present exchanges in both urban and rural areas are now dial and completely unattended with no operators, the telephone companies are finding that in most cases the employment of an operator would be uneconomical to handle calls just for the mobile services such as a mobile operator.

Design Specifications

To meet the growing demands for mobile radio service, especially in rural areas, and in view of the trend toward unattended dial exchanges, the Rural Electrification Administration awarded two contracts for the development of mobile dialing systems.

Motorola has participated in the R.E.A. program and developed a system which is now in its sixth month of a trial installation at Amherst, Virginia.

The R.E.A. specifications included the following main features:

1. Connections into the dial exchange via a regular 10-party subscriber line without any modifications within the exchange.
2. Mobile selections initiated by standard multi-frequency ringing signals.
3. Mobile-to-exchange dialing to be registered into exchange in conventional manner.
4. Mobile-to-mobile dialing by means of the exchange revertive call circuits.

The conventional telephone type supervision such as ringing, dialing, and disconnect should be transmitted over the radio system without any modifications to the standard exchange equipment.

Audio tones in the band up to 3000 cps are used to convey these supervisory signals by radio.

The characteristics of radio wave propagation to and from moving vehicles have to be considered in any mobile system involving tones. Due to multi-path reflections, especially in fringe or weak signal areas, standing wave conditions are often experienced. These conditions may result in gaps or holes in the signal level. Tests have revealed that these gaps may exist for as long as a tenth of a second, or 100 milliseconds, with a vehicle moving at about 20 miles per hour.

In consideration of the above factors, a system must be still capable of proper dialing and signalling. One of the most drastic sins in the telephone industry is to obtain wrong numbers.

Calling a Mobile Unit

The central office station is made up of the exchange termination equipment and the two-way base radio station. The base station is connected as an R.T. repeater except that the transmitter is keyed directly by the exchange and the carrier sense relay is used to signal the exchange.

The signalling required can be divided into two parts. They are, signals to call a mobile from a land subscriber, and signals to dial a land subscriber from the mobile unit.

When a land subscriber dials the telephone number of a mobile unit the automatic telephone exchange places ringing voltage on one side or the other of the line connecting the radio termination equipment with the exchange. The ringing voltage is one of five frequencies within the range of 16 to 66 cycles per second, and the amplitude is between 50 and 150 volts. In order to transmit the ringing information over the radio system to the mobile units the ringing frequencies are translated to a higher frequency. See Figure 1.

The translation is performed by a modulator which is of the carrier suppression type, and the two side bands are transmitted to the mobile units. The side of the line (L1 or L2) determines the frequency of the carrier applied to the modulator.

In the called mobile unit the ring tone receiver (see Figure 2) has two resonant reeds (vibrasponders) detectors tuned to the two side bands. When the mobile unit detects the presence of the two sidebands, it rings a bell in the mobile unit. This ringing will continue until either the land subscriber hangs up or until the mobile operator answers. To answer, the mobile operator picks up the handset and operates the

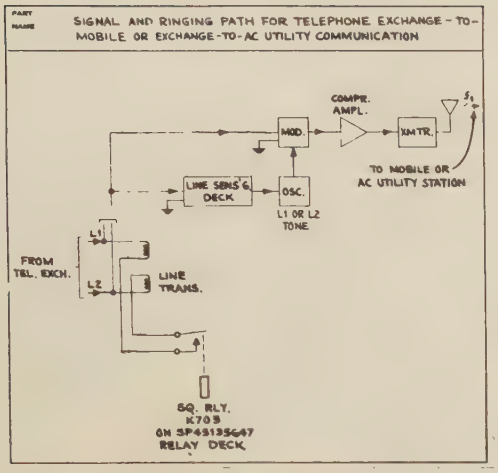

Fig. 1 - Block diagram showing how the ringing frequency is translated.

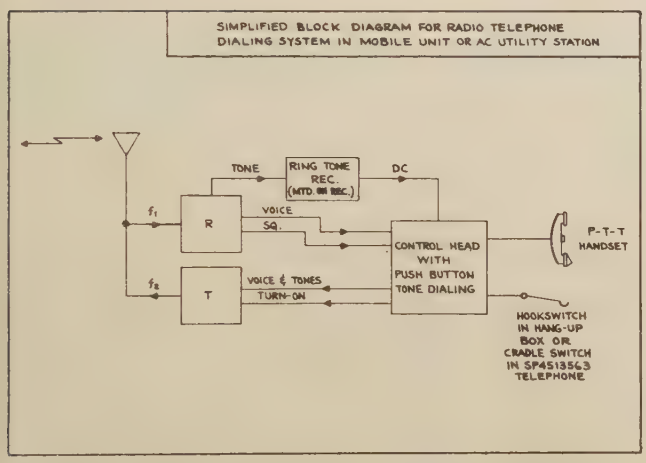
SIMPLIFIED BLOCK DIAGRAM FOR RADIO TELEPHONE DIALING SYSTEM IN MOBILE UNIT OR AC UTILITY STATION
TONE
RING TONE REC. (MTD. ON REC.)
DC
VOICE SQ.
R
T
VOICE & TONES TURN-ON
CONTROL HEAD WITH PUSH BUTTON TONE DIALING
P-T-T HANDSET
HOOKSWITCH IN HANG-UP BOX OR CRADLE SWITCH IN SP45135G3 TELEPHONE

Fig. 2 - Block diagram of the mobile unit.

DECI MONIC	L1 OSC 254.1	L2 OSC 346.7
20 CPS	234.1-274.1	326.7-366.7
30 CPS	224.1-284.1	316.7-376.7
40 CPS	214.1-294.1	306.7-367.7
50 CPS	204.1-304.1	296.7-396.7
60 CPS	194.1-314.1	280.7-412.1

Fig. 3 - One possible set of ringing frequencies with the resultant transmitted tones.

push-to-talk button which keys the mobile transmitter. The carrier is detected by the exchange termination equipment which puts a D.C. closure across the line. This is called the "off" hook condition and it signals the exchange to stop ringing and connect through the calling subscriber.

A chart showing the ringing frequencies and the resultant side bands are shown in Figure 3. By using two lines and four carrier frequencies 20 mobiles can be used on this system.

Dialing from a Mobile Unit

In order to dial from the mobile unit, the mobile operator presses the push-to-talk button on his handset, keying the mobile transmitter. The carrier sense relay in the termination equipment locks up a relay which applies the "off" hook condition to the exchange. This "off" hook condition must remain during the entire call, even though the mobile does not transmit continually during the call.

When the exchange receives the "off" hook condition it turns on the transmitter and transmits dial tone to the mobile unit. This is the signal for the mobile operator to start dialing.

Dial pulses are applied to the exchange as short open circuit pulses on the line. These pulses occur at a rate of 10 per second and have a duration of 62 milliseconds. A group of one to ten of these pulses are required for each digit or letter in the telephone number.

It is clear that if correct digits are to be transmitted over the radio system which may be dropping out for periods up to 100 milliseconds, the digit information will have to be changed to some other form for transmission.

The form chosen is a system of 2 out of 4 tone transmitted one tone at a time. Each tone is transmitted for a duration of 300 milliseconds which is long enough to ride over long drop outs. A fifth tone is transmitted following the two digit tones which gives positive interdigit information. Since only one tone is transmitted at a time, it can fully modulate the transmitter and thus have a better signal-to-noise ratio.

The control head for the mobile unit has a push button arrangement for selecting the digits to be dialed. The operator pushes the desired button and holds it for a moment. The first and second tones are transmitted and automatically timed for the correct tone duration. See Figure 2 and 5. When the mobile operator releases the button, the interdigit tone is transmitted. To tell the operator when he may release the button a tone is applied to the receiver in the hand set. This tone also keeps the operator from rushing the system.

In the termination equipment the tones are detected and sequence is determined which puts the desired digit into a memory device. When the interdigit tone is received a pulse genera-

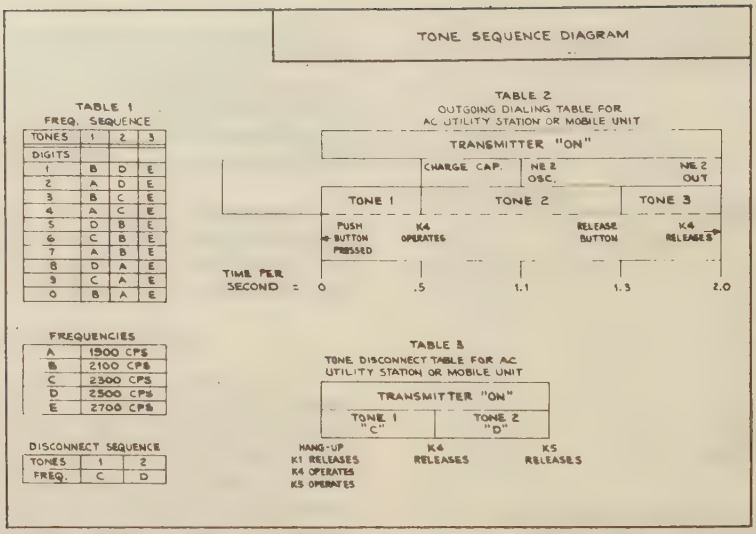

Fig. 4 - This chart shows the sequence of operation as well as the approximate time involved.

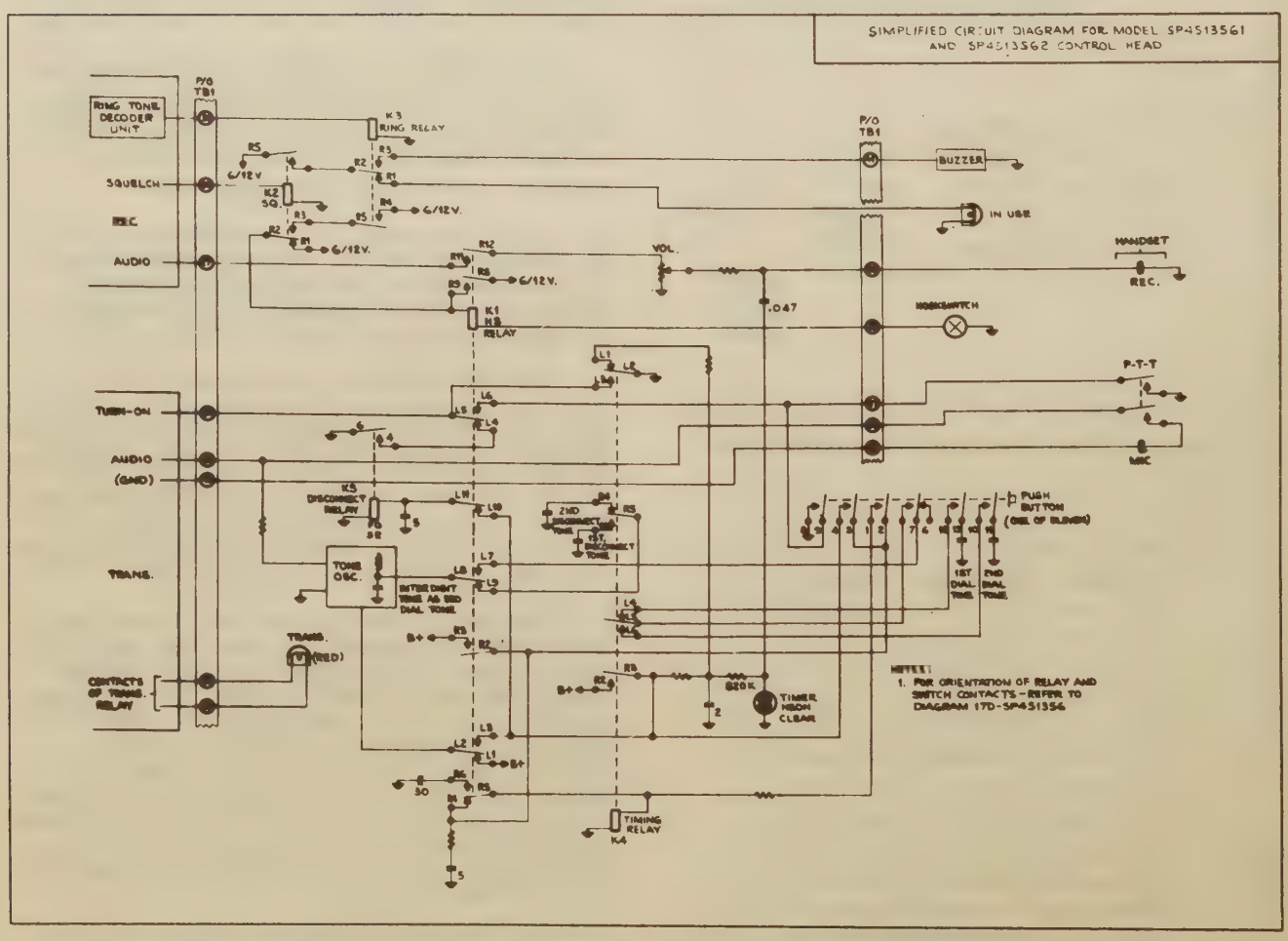

Fig. 5 - Simplified diagram of the control head. Note that all push buttons are wired the same except for tuning capacitors.

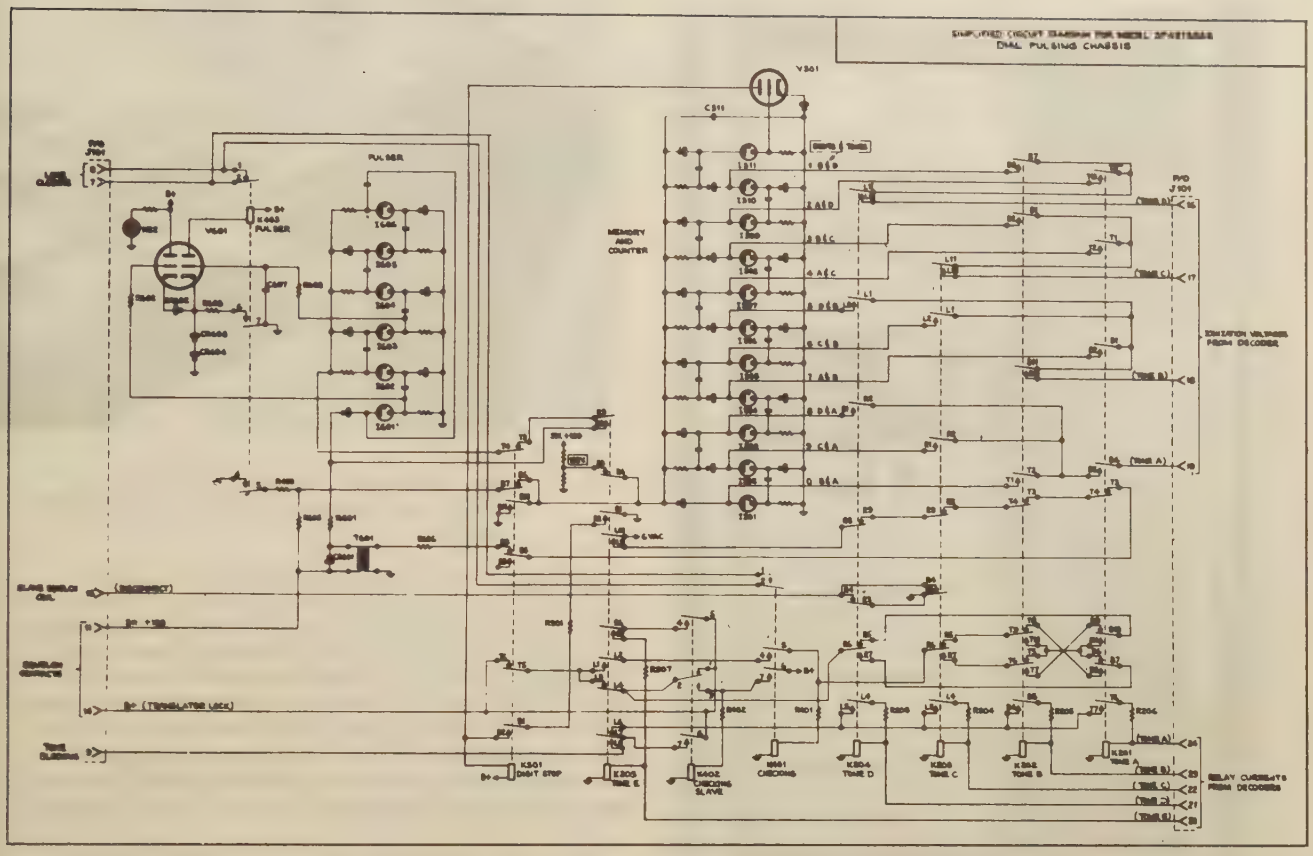

Fig. 6 - Simplified circuit diagram of translating circuits.

tor pulses the line the correct number of times. A simplified diagram of this circuit used is shown in Figure 6. The sequence of operation is shown in Figure 4.

As each tone is received it operates its corresponding relay and applies a corresponding ionization voltage to the relay circuit. As an example, when Tone "A" is received relay K201 operates and 170 volts is applied to Terminal 19 of J101. When the "A" tone stops and the "B" tone starts the relay K201 remains operated for a short time, but the ionization voltage changes to Terminal 18 of J101. With two relays operated, there will be a path for the ionization voltage to memory and counting chain. The ionization voltage will ionize the neon lamp I304 corresponding to the digit seven. When the interdigit Tone "E" is received the pulse circuit is actuated which counts the 60 cycles per second power frequency and pulses the line with the correct pulse duration at exactly 10 pulses per second. The counting chain in the pulser always starts with lamp I601 ionized. The counting circuits operate as a shift registor. That is, the ionized lamp steps one position each time a negative pulse is applied to the circuit. The transformer T601 supplies the negative pulses to drive the counting circuit in the pulser. When lamp I603 is ionized relay K403 operates and stays operated until lamp I601 again is ionized. Each time the line is pulsed the memory counting chain is pulsed and the ionized lamp steps one position towards I311. When the last pulse for the desired digit has been pulsed I311 ionized, V301 conducts and relay K501 operates which resets the circuits to receive the next digit.

Provisions have been made in the circuits so that each part of the tone code must be received before a digit will be pulsed into the exchange. Thus when the mobile gets so far into the fringe area that one or more of the tones are lost a wrong number will not be dialed.

Since the four tones give twelve combinations, two of the combinations are used for disconnect

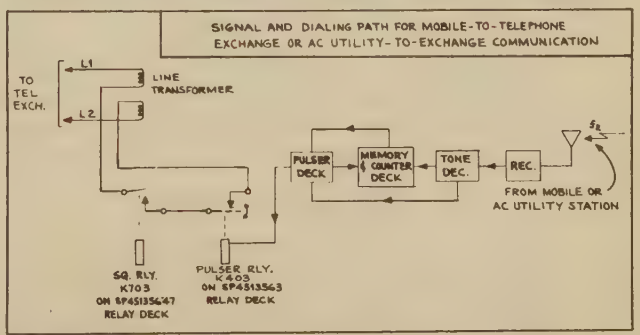

Fig. 7 - Block diagram of the central office termination equipment.

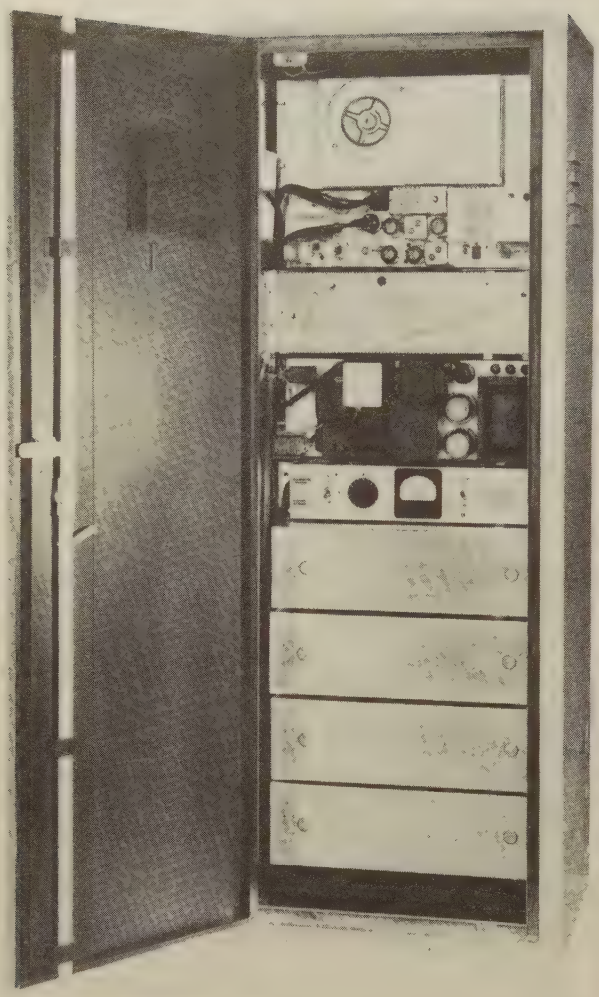

Fig. 8 - The central office ratio station and termination equipment.

or on hook. When the mobile operator hangs up the handset the mobile unit automatically transmits the two disconnect tones which gives the exchange an "off" hook condition. If the mobile unit has moved out of range, a timer will disconnect the exchange.

To make a call from car to car the same procedure is used as is used to call someone on your

Fig. 9 - Mr. Dennie of the Central Virginia Telephone Company using the telephone system.

party line. This requires using the standard revertive call portion of the exchange whether it is the use of a special code or the use of standard directory numbers. The operator calls the telephone number of the other car and the exchange will ring the number. Rather than handing up when the calling party gets the busy or high tone the operated P.T.Y. button which transmits disconnect tones but over-rides the lock out so that the calling party can monitor the ringing.

In this system if it is in use all mobile units other than those making or receiving a call are blocked from being put into use. A carrier sense relay in the mobile unit provides the block whenever the base station transmitter is transmitting. The ringing of the mobile opens the blocking circuit of the called unit, allowing it to answer.

Conclusions

The field test in Amherst, Virginia, has shown that the tone duration is correct. The operators of the mobile units report that the push button dialing is convenient and requires only a few minutes to learn its operation. Additional mobile units are being added to the original test installation by the Central Virginia Telephone Company.

THE GAUSSIAN CURSE-TRANSMITTER NOISE LIMITS SPECTRUM UTILIZATION

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Summary

In a modern radio system, where attention has been given to receiver selectivity and spurious response and transmitter "sideband-splatter", it has been found that transmitter noise spectrum output may limit the ability to communicate over large systems gains. An absolute method of measurement of transmitter noise spectrum amplitude is described and the effects of noise in terms of required physical and frequency spacing is shown. Analysis of the measurements indicates that attention to transmitter design can produce a significant reduction in noise spectrum amplitude.

Introduction

Recently communications engineers have shown a renewed interest in schemes of reduced transmitter spectrum occupancy. This increased interest has been primarily engendered by the almost phenomonal increase in band occupancy, and its attendant adjacent channel problem, which has occurred within the past few years. The problem has been particularly severe among the mobile radio services where the mobility of the receiving equipments has placed communication in the double jeopardy of weak desired signals and strong adjacent channel signals. Several recent investigators have called attention to the problem and indicated the characteristics of receiver performance and transmitter spectrum which influence interference.[1,2] Among the various methods of modulation it has been shown that one of the prime causes of interference, modulation sidebands, can be reduced by attention to deviation, modulator audio bandpass, and amplifier linearity. By way of mention, and usually as somewhat of a side issue, the presence of transmitter noise has been mentioned. This is a rather logical way for the interest to develop, since the problem of modulation sidebands was initially of greater severity, now however, it is time to investigate another limiting factor in system performance which bids fair to be just as severe a deterrent to communication as sideband splatter.

Transmitter Noise

In many cases transmitter noise, rather than any other difficulty, has been the thing which reduced the range of reliable communication. Why then is it that it has so long escaped notice as a primary offender? The reason is that, in the close spaced channel situation where noise is the offender, many transmitters which are not up to the latest state of the art obscure the noise in modulation splatter. Further, and even more insidious, those transmitters which are "clean" in close and are causing only noise interference create their interference as noise which is indistinguishable from the receiver noise normally attendant to a fading received signal. Thus the noise interference is often mistaken for a weak signal and the loss of communication is falsely attributed to propagation vagaries.

Comparison of Noise With Other Effects

The best way to illustrate this subtle situation is to listen to the effects of such interference as purposely created in the laboratory and recorded on tape. First, let us listen to a very close spacing so that interference due to sideband splatter is received. This is clearly identifiable as the characteristic "monkey-chatter". Next let us move even closer to illustrate loss of reception due to receiver desensitization by a strong unmodulated carrier getting into the desired passband. Modern receiver design has minimized this effect. This you will note has the effect of "reducing the modulation" or, if very strong, of completely capturing from the desired signal. If we were to go even closer we would also get some very evil effects from heterodynes between desired and undesired carriers falling in the audio passband of the receiver. Both these types of interference are readily identifiable. Now let's move out again in frequency with a modern receiver until we leave the sideband splatter effects behind and pass into that region of the transmitter spectrum where transmitter noise predominates. As we increase the strength of the undesired transmitter the received signal is obscured by transmitter noise. Note how this sound like the noise due to a weakened signal in the receiver. For comparison let's listen to the case of no interfering signal but simply reduce input to the receiver. It's easy to see why the effects of the transmitter noise were not pinpointed in early investigations. While the level of transmitter noise below the carrier is quite a goodly number of decibels, it does exist, and it has been shown in analytical studies that for a carrier modulated by Gaussian noise, with an index of modulation much less than one, the power density falls off at a rate of six db per octave of frequency separation from the carrier frequency. For phase modulation it can be likewise shown that the spectrum of noise is flat with respect to frequency.[3,4]

Method of Measurement

Quantitative measurements of transmitter noise are not easy to obtain. Basically the reason for this is contained in the limitations of receivers. To investigate this, let's turn to figure #1. Here we show the measurement procedure required for determining the absolute

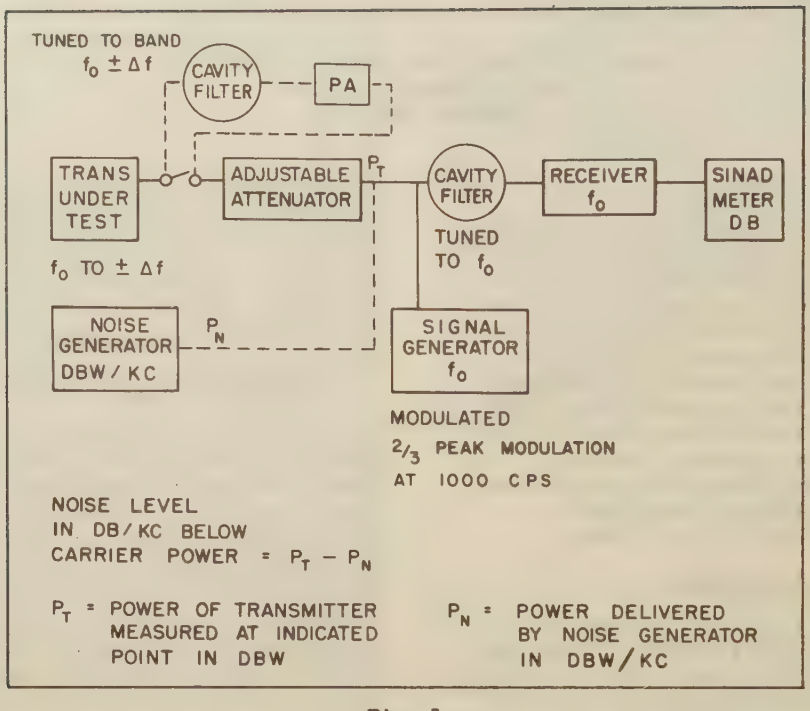

Fig. 1

level of the noise power density of the transmitter spectrum. As is shown in this figure, the level is determined by a method of substitution which helps minimize errors attendent to this type of work. In operation, the transmitter under test is connected to a receiver, usually insured against desensitization by a front end cavity, through a suitable attenuator. With the noise generator turned off, the transmitter is turned on, without modulation, and the attenuator adjusted to deteriorate a 12 db SINAD ratio, previously introduced by the desired signal generator at 2/3 system modulation, until a SINAD ratio of 6 db is produced. P_t, the power delivered to the receiver in db w by the transmitter may be measured by any suitable means. With the transmitter turned off, the noise generator output level is raised until the same 12 to 6 db SINAD deterioration is experienced. P_n, the power delivered by the noise generator to the receiver in db w/kc may be read from the generator calibration. The noise level in db/kc below the transmitter carrier power is then P_t-P_n. This particular method of transmitter noise measurement has the advantage that it is not dependent upon bandwidth or frequency and therefore allows an absolute comparison of the figure of merit of any transmitter with respect to any other. Other similar systems of measurement for a relative indication suitable for system comparisons on any particular frequency have been described elsewhere. [1] Certain precautions are necessary in order to insure the validity of absolute transmitter noise measurements. For instance, you must be sure that the receiver selectivity is good enough so that desensitization due to carrier is not occurring. This can be checked by adding a front end cavity and noting that no change in desired performance occurs. It should be noted that this increased selectivity must not be sharp at the nose so that the receiver passband attenuation is materially altered, insofar as response to the desired signal is concerned. In setting up for measurement it should be possible to attenuate the signal through the attenuator by 10 to 12 db more than the point of measurement--this may require the use of a shielded room or very careful attention to the reduction of direct radiation. When measurements for PA noise only are made this is accomplished by using very sharp filtering between the driver and the PA. The adequacy of the filtering between the driver and the PA may be shown by providing additional cavities. When the attenuation of the cavity is 9 db greater than the reduction of noise the observation is correct to within approximately half a db of its ultimate value.

Results of Measurements

Let's now examine the results of some transmitter noise measurements made in accordance with the described method.

Figure #2 shows measurements made on a 45 megacycle transmitter. This transmitter had a multiplication of 12 with a crystal frequency of about 3.75 mc. While not modulated, it had provisions for frequency modulation by phase deviation. The power output was about 250 watts. Reference to curve #2 shows levels of measured noise for power amplifier alone and power amplifier plus exciter. At about 800 kilocycles the curve of PA alone is improved only 3 db by adding the cavity-which shows that the exciter and PA are about equal in producing noise at this

point. The filter was providing about 23 db attenuation at 800 kc. Examination of the curves closer in seems to indicate that exciter, with its multipliers, is about 18 db worse noisewise than the PA alone. The spectrum of noise of the exciter appears to fall off at a rate of 6 db/ octave up to about 130 kc. Beyond this the fall off is more rapid, presumably due to the selectivity of the multiplier stages.

Figure #3 shows the noise spectrum from a 160 mc 250 watt transmitter with a multiplication of 24. Again, while not modulated, it had provisions for frequency modulation by phase deviation. Reference to the upper curve shows that normal transmitter, PA plus exciter, has the same 6 db/octave slope as the previous 45 megacycle transmitter but its level is about 13 db stronger. Reference to the lower curve of figure 3 shows that the power amplifier alone is itself about 5 db noisier than the 45 mc PA. Note also, that the point at which the spectrum slope exceeds 6 db/octave has been moved out to beyond 200 kc as a result of the lower selectivity of the high frequency multipliers.

Figure #4 shows noise spectrum measurements made on two single sideband equipments. The upper curve is for a 450 mc single sideband converter/exciter. Its noise level is at about 63 db/kc below carrier power. This is approximately 34 db worse than the 45 megacycle equipment in figure 2. The next curve down in figure 4 shows a 30 mc single sideband transmitter. This transmitter is about 14 db worse than the 45 mc transmitter. In each case the slopes of the power spectra of these two transmitters show the effects of exciter stage selectivity distributed at various frequencies and possibly the effects of both frequency and phase modulation by noise. The bottom curve on figure 4 shows the 30 mc linear amplifier alone. Its slope seems to indicate that linear amplifiers do not have the 6 db/ octave characteristic of class C amplifiers and multipliers

Figure #5 shows the results of an investigation to ascertain how the noise spectrum from a high frequency transmitter could be reduced. In this case we have constructed an equipment with a multiplication of only four, two doublers and have compared it to one with a multiplication of twelve, provided by two doublers and one tripler. As can be seen, an improvement of 20 db was realized by reducing both the number and order of multipliers. The multiplication by four transmitter probably had increased slope due to multiplier selectivity because it already approached the PA noise performance.

Functional Effects

Figure #6 shows the deletericus effects of transmitter noise in terms of the antenna spacing, which would be required between a fifty-watt-transmitter and a receiver at any given frequency spacing. For example, if a 3 db loss in signal to noise ratio is permissible in a receiver of .5 microvolt sensitivity due to noise from a 50 watt transmitter, then

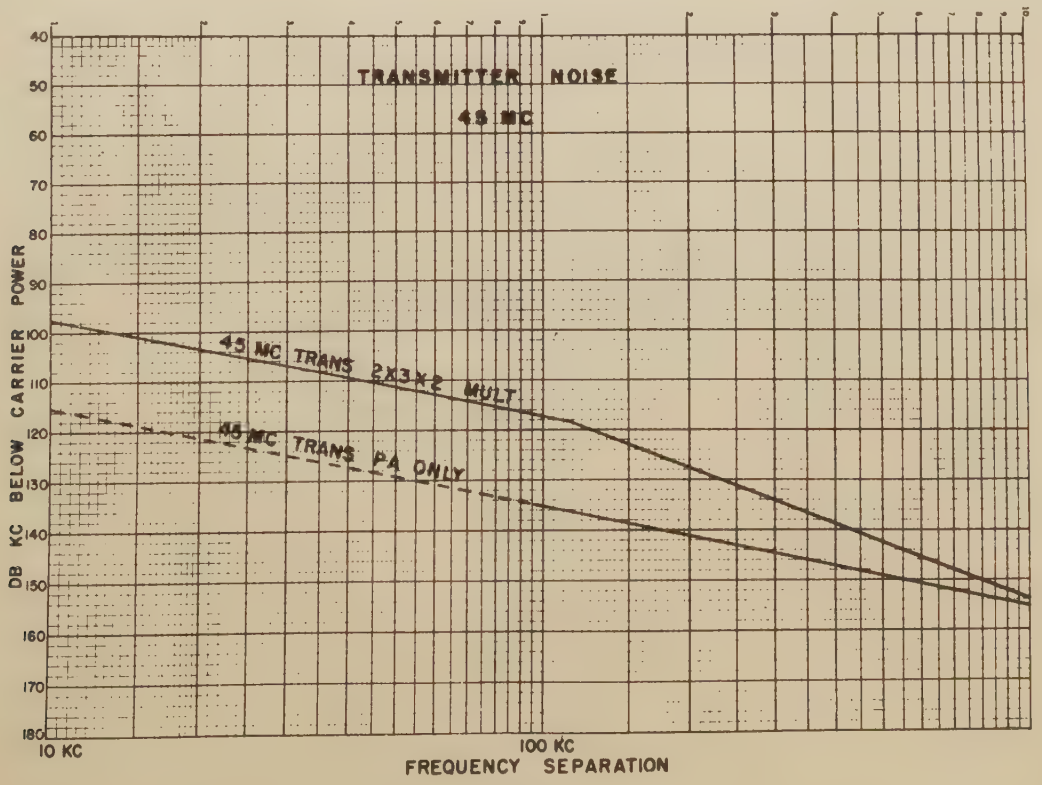

Fig. 2

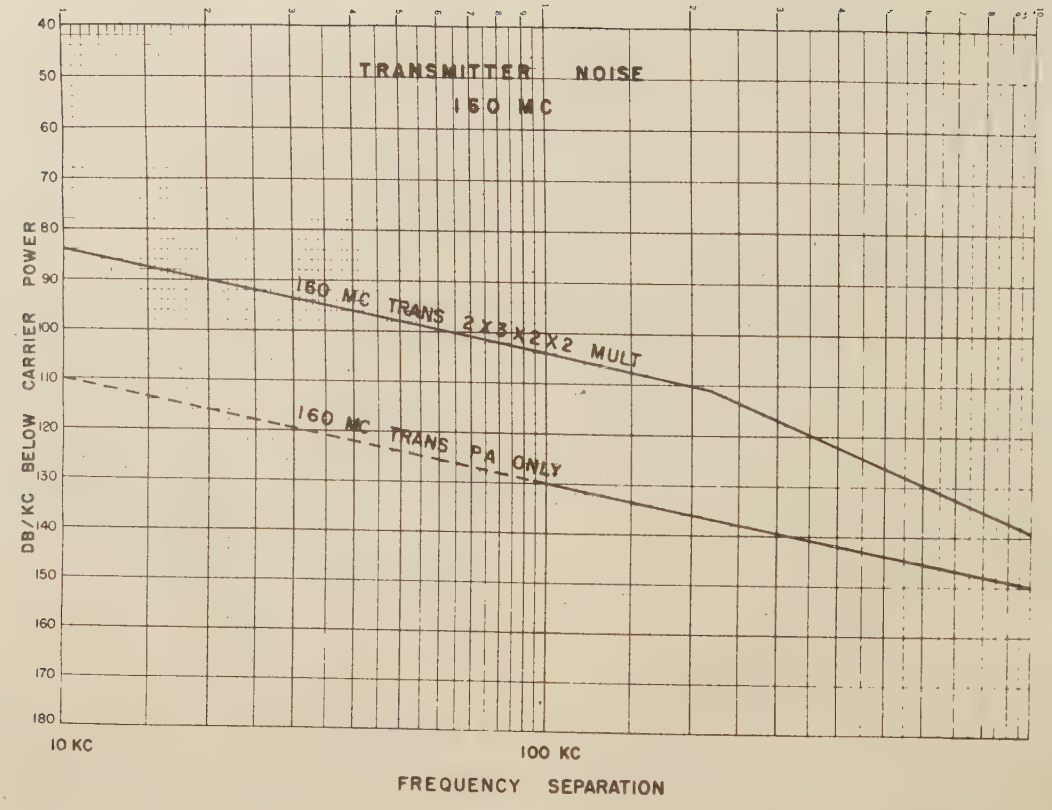
TRANSMITTER NOISE
160 MC
160 MC TRANS 2X3X2X2 MULT
160 MC TRANS PA ONLY
DB/KC BELOW CARRIER POWER
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
10 KC
100 KC
FREQUENCY SEPARATION

Fig. 3

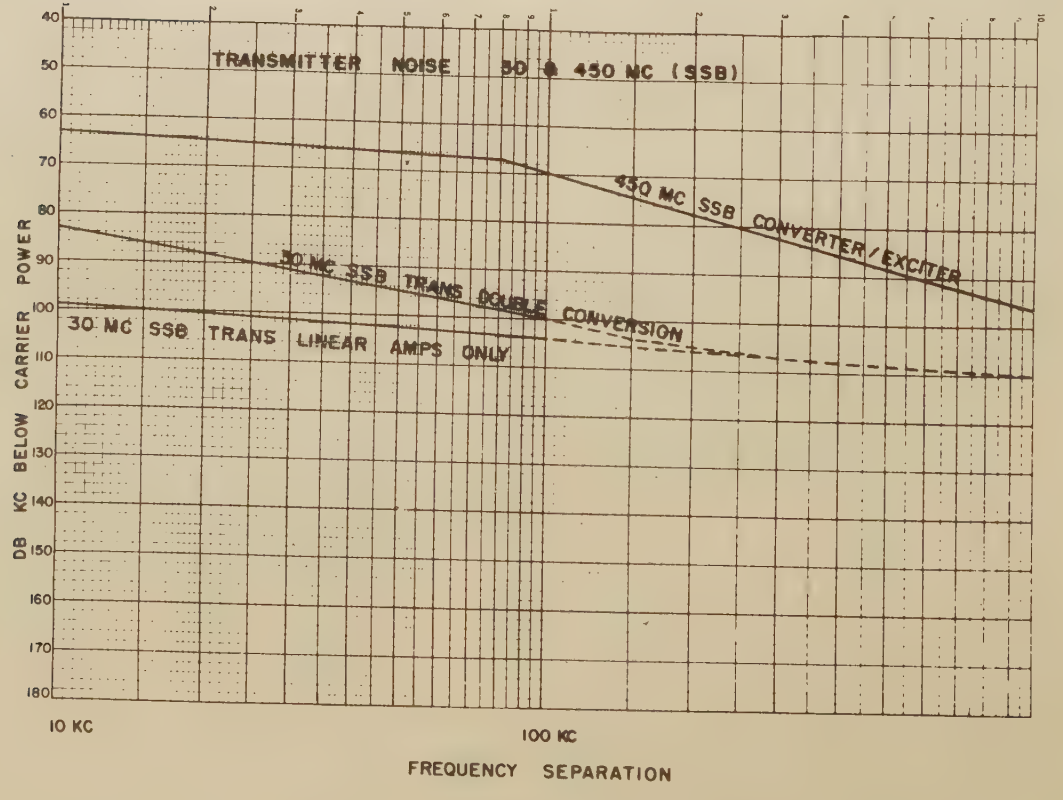
TRANSMITTER NOISE 30 & 450 MC (SSB)
450 MC SSB CONVERTER/EXCITER
30 MC SSB TRANS DOUBLE CONVERSION
30 MC SSB TRANS LINEAR AMPS ONLY
DB KC BELOW CARRIER POWER
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
10 KC
100 KC
FREQUENCY SEPARATION

Fig. 4

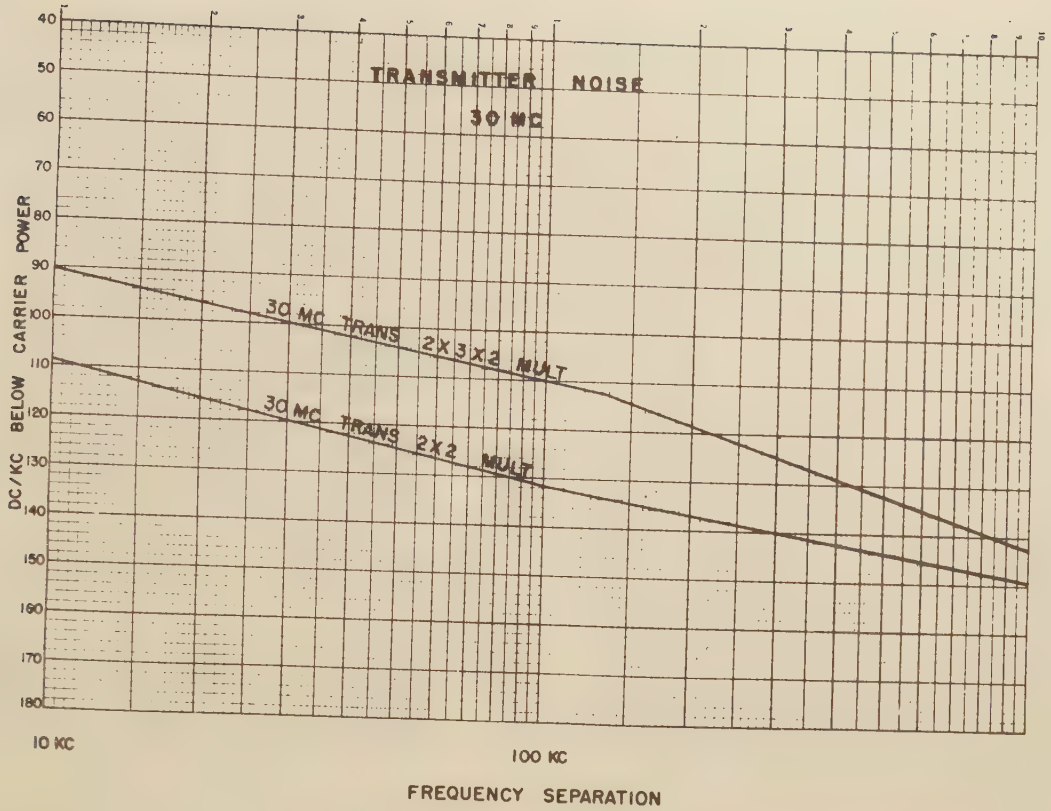
TRANSMITTER NOISE
30 MC
30 MC TRANS 2X3X2 MULT
30 MC TRANS 2X2 MULT
DC/KC BELOW CARRIER POWER
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
10 KC
100 KC
FREQUENCY SEPARATION

Fig. 5

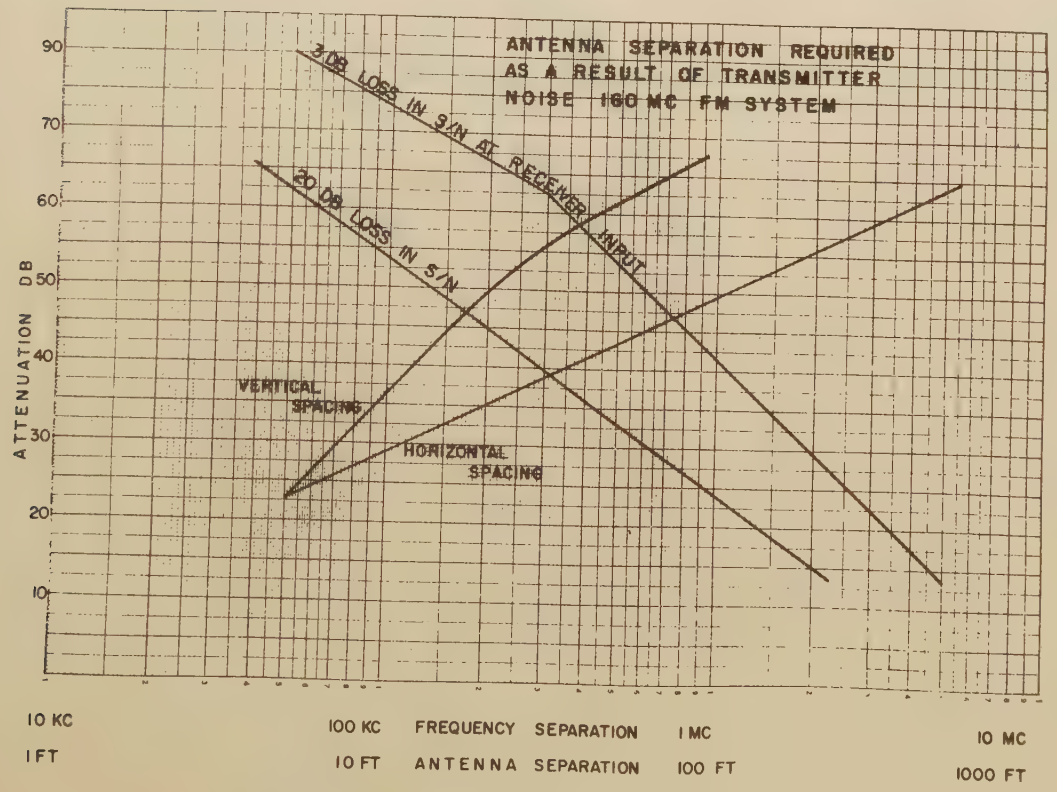
ANTENNA SEPARATION REQUIRED
AS A RESULT OF TRANSMITTER
NOISE 160 MC FM SYSTEM
3 DB LOSS IN S/N AT RECEIVER INPUT
20 DB LOSS IN S/N
VERTICAL SPACING
HORIZONTAL SPACING
ATTENUATION DB
90
70
60
50
40
30
20
10
10 KC
1 FT
100 KC
10 FT
FREQUENCY SEPARATION
ANTENNA SEPARATION
1 MC
100 FT
10 MC
1000 FT

Fig. 6

at a frequency spacing of 600 kc an attenuation of 50 db is required. This is equevalent to a vertical antenna spacing of 20 feet, or a horizontal spacing of 100 feet. In the situation which is rapidly becoming very common, a whole series of transmitters and receivers mounted on one tall mountain or building, it is easy to see how important a factor transmitter noise might become. This curve shows how drastic a move, spacing or frequencywise might be required to maintain reasonable performance.

Conclusion

From the various curves which we have seen there are a number of interesting conclusions which can be drawn. Generally speaking, the more multipliers or mixers which are used, the more the likelihood of a bad noise performance. This means that in general we would expect the noise spectrum to become more noticeable as we progress upward in frequency. The hope of escaping these consequences through the mix, linear amplifier approach does not seem good since the linear amplifiers have more noise output than the class C. We have seen that reducing the number and order of multipliers to a minimum before the class C output stage produced the quietest performance of any.

The investigation done here has only scratched the surface of a very complex problem and only pointed the way to one partial solution to a dilema which is likely to grow more severe with each new frequency allocation. The authors hope they have helped point the way to a potentially very fruitful field of investigation.

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VEHICULAR COMMUNICATIONS

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1952-1957

The Institute of Radio Engineers, Inc.
1 East 79th Street, New York 21, N. Y.

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